GENERAL MOTORS Engineering JOURNAL

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for educators in the fields of engineering and allied sciences

RAILWAY POWER

On Ideas and the Engineer

AT HIS DESK, drafting board, laboratory, or wherever he may be in industry, the engineer has the job of producing ideas.

To be sure, his mind has been well trained for many other tasks. He has been taught, for example, to solve problems according to a definite pattern. Simply stated, the pattern consists of defining the problem, assembling the facts, appraising the facts, and making a decision based on the appraisal. The engineer's training also equips him to apply the fundamentals of physics and the other sciences, since most of the problems he sees require this kind of solution. He is accustomed to analyzing in terms of facts and material things.

But this kind of thinking is routine for him. When, on the other hand, he can produce ideas of his own for the solution of a problem, this is the real key to the engulfing satisfaction in his task and, indeed, is one of the reasons his employer values him. The engineer becomes, then, an "idea man"—one who can be creative.

The problems that come before him range from the workaday tasks in completing a design or a process to the "problem" of providing a new or improved product which the public wants. For example, the public's taste in automobiles changes rapidly. In years past, the motorist began to demand the elimination of manual gear shifting. The engineer's problem there was to meet that demand with the design of a satisfactory automatic transmission which could be built in production quantities. Working independently, General Motors engineers supplied a great many ideas to solve this problem. The answer came in three basic designs for automatic transmissions which were produced and put into service. The problem was solved and today's GM cars and trucks continue to use the same fundamental types in improved versions—the result of still more ideas along the way.

The public's taste also calls for frequent new designs in motor cars. To satisfy this taste, the engineer must supply ideas of how a body structure with different openings or a different shape can be designed for strength, safety, and economy. New manufacturing techniques are required too. Again, his ideas for a new method of welding body panels or a new method of body assembly help to solve this problem.

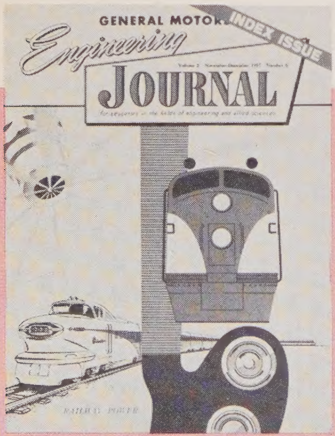
On the other hand, the engineer's problem may deal merely with an individual component like achieving a special motion in a mechanism or designing an ordinary mounting bracket. The list can be endless—yet, in every case he needs to be ready to integrate original ideas into his more routine thinking processes.

When the engineer completes his formal education as a student, he also completes a period of his life in which the pattern has been one of maximum direction. As he changes from college student to employe, the amount of direction he receives grows less and less. Thus, as he progresses, he becomes not a routine worker but one who sees in every task an opportunity to make use of his own creativity. Initiative and responsibility are now expected of him.

The engineer's experience teaches him that many of his ideas are not accepted, many have been thought of before, many will be modified in the process of discussion with others on his working team. However, a certain number of his ideas are used and therein lies the value of his work and the sense of personal satisfaction he derives from it.

Doing an engineer's job requires a number of important qualities. One of these is the ability to produce an idea. That is where progress makes its start.

John F. Gordon,
Vice President and
Group Executive



THE COVER

Progress in railway motive power is the subject of this issue's cover—another by Artist John Tabb portraying developments in transportation. The Diesel fuel injector symbolizes the importance of the Diesel engine to the nation's railroads where today the Diesel locomotive is as common as the familiar railroad semaphore. Engineering improvement over the years has resulted in higher traction motor ratings and Diesel engines with increased brake horsepower, lowered specific fuel consumption, and good fuel economy. Standard components have afforded greater reliability and flexibility.

Future possibilities for Diesel powered trains are suggested by the sketch of the new General Motors lightweight train—built at the request of railroad officials to demonstrate the suitability of a number of new features for improved economical railroad service.

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The GENERAL MOTORS ENGINEERING JOURNAL is published every other month by the Educational Relations Section of the Department of Public Relations, General Motors Corporation, and is intended primarily as a medium for presenting to the field of engineering education the results of General Motors research and engineering developments both in the product and production fields.

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How Sound Affects Vibration in Modern Aircraft Engines

By JOHN M. WHITMORE,
WILLIAM R. LULL, and
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Allison Division

High level sounds of jet aircraft induce mechanical failures

In the development of modern jet aircraft, the engineering problems encountered have been numerous. Some of these have been new problems, while many have been old ones reappearing with a new significance. High in this latter category are problems associated with sound phenomena in the modern aircraft and in its components. The descriptive terminology of sound commonly found in present-day aeronautical engineering contains many former terms used with a new ultra-meaning, such as compressor "whine," augmentor "howl," propeller "roar," fuselage "scream," and the indescribable explosive supersonic barrier "crashing" and "banging." The unwanted by-product of aeronautical engineering is noise—noise of such magnitude as never before encountered in man-made machines. The term *sound* or *noise* is limited in this discussion to vibration or pulsing wave motion in gaseous media (without regard to its degree of flow), from the lowest frequencies through the audible range. This noise not only introduces problems related to its physiological and psychological effects on human beings, but it may become the source of engine inefficiencies and mechanical damages. An understanding of some of these problems can be gained by an analysis of a specific case of sound-produced damage in the Allison J33 turbo-jet engine, together with an account of the design modifications introduced for its control.

Fig. 1—This is the classical example of mechanical damage induced by resonance with sound. The shattering of the glass tumbler demonstrates the effect of periodic phase shifting of the excitation. The tumbler was excited at its fundamental resonant frequency by sound wave bombardment, using an unphased siren as the exciter. The tumbler shattered when vibrational overstressing caused it to reach its failure stress level. It is interesting to note that when this demonstration again was set up with identical conditions—with the substitution of a phased siren for an unphased siren—the failure stress level of the tumbler could not be reached.

TRADITIONALLY, the design engineer has been inclined to attach little significance to the sounds produced by machines, other than the necessity of suppressing their nuisance character to an acceptable level compatible with use and environment. As a drain on the machines producing them, the highest sound levels encountered in the audio range—outside the field of aviation—have dissipated insignificant amounts of energy. Calculations of the audio power of 100,000 madly cheering football fans places it roughly in a 25-watt to 40-watt class. The energy converted by Niagara Falls into sound radiation is an inconsequential fraction of its total energy output. The highest machine-created sound levels, prior to jet aircraft, have been in the range of 130 decibels (db). Many scales were calibrated no higher.

Decibels are the units in a logarithmic scale which arbitrarily takes its zero point at the lowest sound intensity audible to the average person. This level has a sound energy rate of 10^{-16} watts per square centimeter. A 130-db sound intensity level would have a power of 10^{-3} w per sq cm. A whisper at 5 ft produces a sound intensity level of 25 db; the average factory noise is 75 db; heavy city traffic may be 95 db; and a boiler factory produces 110 db. The threshold of sound level painful to human ears is 130 db.

Recent Rapid Increases in Sound Levels

With ever increasing power in modern aircraft, the sound level has been mounting steadily, and will probably continue to do so. In engine test cells, in the vicinity of the jet stream or within a few feet of certain propellers, many sound measurements in Allison Division's labora-

tories of 160 db and higher are now being recorded. Roughly, this corresponds to an energy transmission by sound compressional waves of 1.2 horsepower per square foot at the measuring point. If this level should be increased to 170 db, the sound energy dissipation rate would increase to 12.0 hp per sq ft. With a 160-db sound level existing on a uniform spherical wave front 10 ft from a radiation point source, the sound radiation rate at the source would approach 1,500 hp. On a linear scale, it means that modern aircraft sounds have increased in energy content by a thousandfold over those sounds previously encountered in man-made machines. Fig. 1 illustrates the classical example of mechanical damage which may be induced by resonance with sound. The glass tumbler was excited at its fundamental resonant frequency by sound waves from an unphased siren. When vibrational overstressing caused the tumbler to reach its failure stress level, the glass shattered.

Acoustical Radiation Losses Become Formidable

VonGierke reports tests of airplane propellers with tip Mach numbers of 1.3 in which the acoustical radiation energy losses reached 10 per cent of the total energy delivered, and model tests in which such losses reached 30 per cent.[1] (The *Mach number* of a body is equal to the velocity of that body divided by the speed of sound in the atmosphere through which it is moving.)

The traditional approach to sound has dealt largely with vibrating solids as the radiation source or with relatively simple vibratory patterns of fluids. In aeronautical engineering, much of the sound has its origin in aerodynamic excitations at high speeds, high temperatures, and complex turbulent conditions. Quantitative measurements of sound energies having their source in the jet stream have been few. VonGierke, Parrack, Gannon, and Hausen reported measurements in which 1 per cent of the kinetic energy delivered to the jet stream was transformed into acoustical radiation—finding that it increases with the sixth power of the jet exit velocity.[2] Allison's engineers have made no direct efficiency studies such as these, but rough calculations based on spatial surveys of sound intensity around the engine would tend to indicate that radiation of such proportions is highly probable.

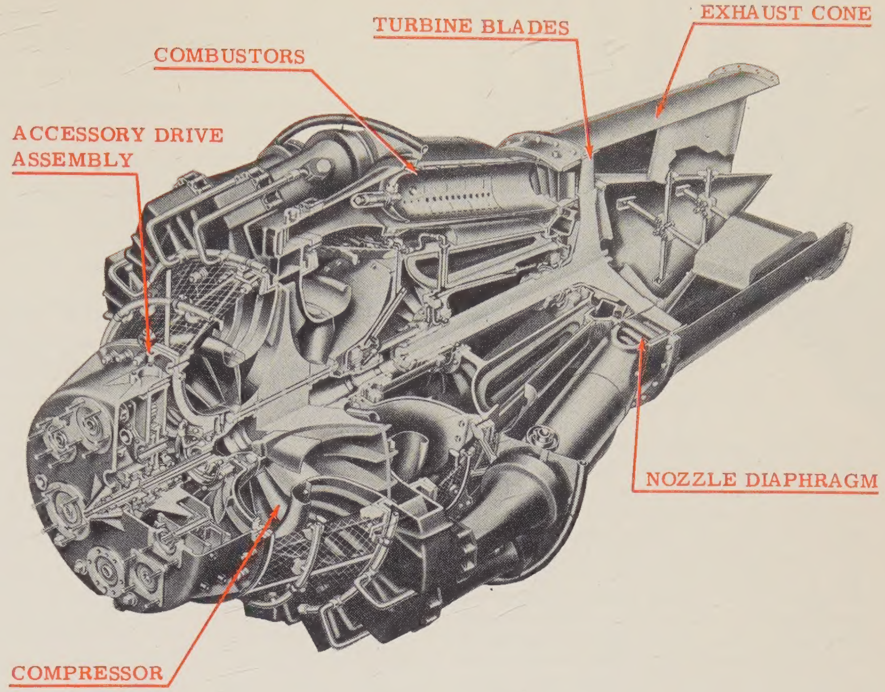


Fig. 2—This cutaway view of the Allison J33 turbo-jet engine shows the five major sections: accessory drive assembly, compressor, combustors, turbine unit (including nozzle diaphragms), and exhaust cone. The compressor raises the inlet air pressure and discharges the air into the 14 combustion chambers arranged symmetrically around the engine. The fuel enters the combustion chambers, is mixed with air, and burned. The exhaust gases leave the combustion chamber through a nozzle diaphragm, strike the turbine blades, and emerge through the exhaust cone. The turbine furnishes the drive power for the compressor and accessories.

Engine Damage Induced by Noise

With such high sound levels, another factor is introduced into the jet aircraft which has never before proved very significant. This factor is the resonant response of one part of an engine to the acoustical radiation from another. In its more common and obvious form it has appeared as failure of wing structure and fuselage due to fatigue brought on by excessive resonant vibration with engine-produced sound. Erratic behavior of sensitive relays and failure of electronic tubes have been traced to acoustically excited resonant vibration.

It is with such phenomena inside the engine, and their control, that this report specifically deals. This paper describes a typical case of how sound affects the vibration of a modern jet aircraft engine and outlines the development of a modified engine design set up to cope with such conditions.

Turbine Blade Vibration in J33 Engines

In turbo-jet engines, turbine blades have been most susceptible to failure because of the high stresses induced by vibration. The high speeds and powers associated with the necessary structural lightness of the parts have made the vibration problem a serious one.

In the earlier designs of the Allison J33 turbo-jet engine the turbine blade vibratory stress level, in its single-stage turbine, was undesirably high. Early in 1950, during experimental testing several blade failures were reported. A concerted plan of action in research, design, and testing was initiated in an attempt to solve this problem.

The Allison J33 turbo-jet engine is composed of five major sections. Arranged from front to back, as shown in Fig. 2, they are: accessory drive assembly, compressor section, combustors, turbine unit, and exhaust cone. The centrifugal compressor raises the inlet air pressure and discharges the air into 14 combustion chambers arranged symmetrically about the engine. Here fuel is introduced, mixed with the air, and burned. The exhaust gases leave the combustion chamber through a nozzle diaphragm, strike the turbine blades, and then emerge from the engine through the exhaust cone. The thrust is developed from the gaseous molecular momentum change at com-

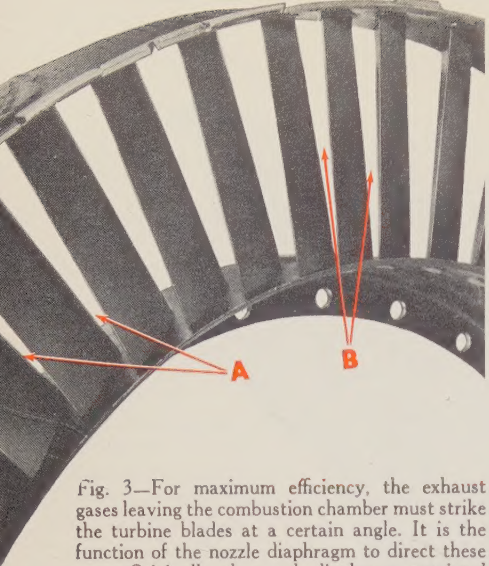


Fig. 3—For maximum efficiency, the exhaust gases leaving the combustion chamber must strike the turbine blades at a certain angle. It is the function of the nozzle diaphragm to direct these gases. Originally, the nozzle diaphragm consisted of 48 evenly spaced vanes directly in front of and near the periphery of the bladed turbine wheel. (*A* indicates the phasing obtained with evenly spaced vanes.) In the modified design, 49 vanes were used to break up the regularity of the 48-vane arrangement so that during one-half of its revolution a blade would receive wave energy pulses out of phase by 180° from those in the other half. (*B* indicates phasing obtained with unevenly spaced vanes.) Tests showed that the stresses in this modified 49-vane design were in the $\pm 5{,}000$-psi to $\pm 10{,}000$-psi class—representing a stress decrease of 50 per cent to 75 per cent over the original design and resulting in substantial decreases in turbine blade failures.

bustion. The turbine furnishes the drive power for the compressor and accessories.

When the combustion gases strike the blades of the turbine rotor, efficiency of operation requires that the gases be directed against the blades at the most advantageous angle. It is the function of the nozzle diaphragm to give the gases the angular deflection required to secure this result.

Originally, the nozzle diaphragm consisted of 48 evenly spaced vanes directly in front of and near the periphery of the bladed turbine wheel. Each vane is slanted at the optimum angle for gaseous impact against the rotating blades (Fig. 3).

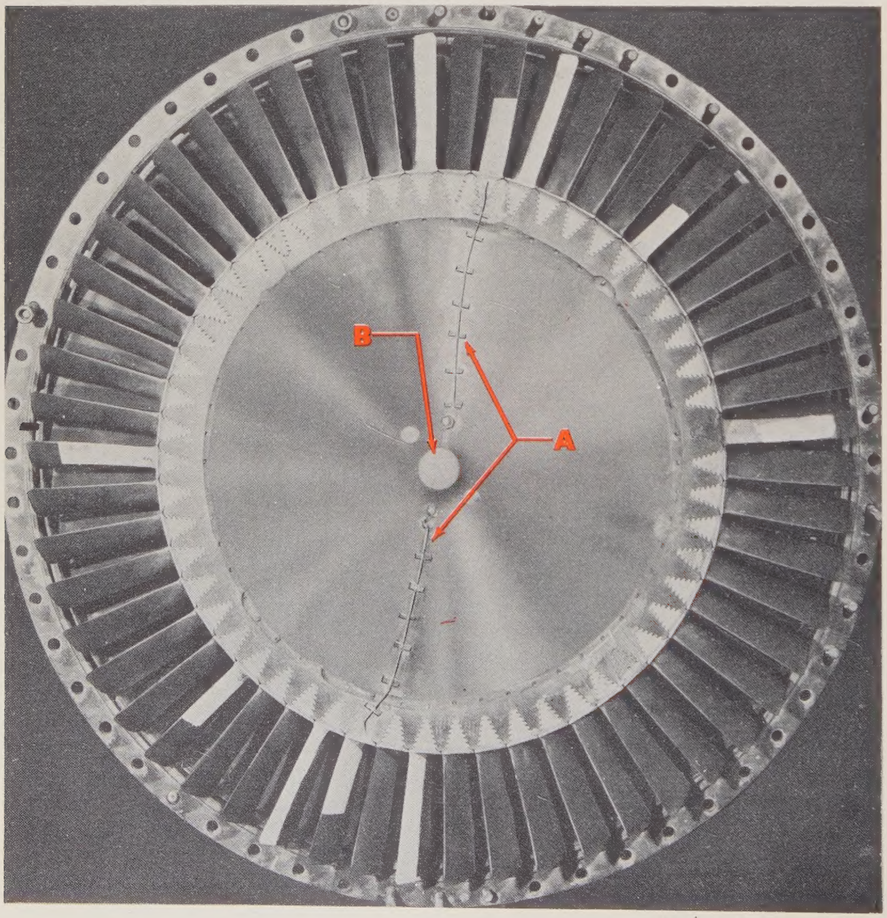
Probable Cause of Vibration

Because of the 14 burners and 48 vanes, the heated gases do not flow steadily and continuously against the blades as they rotate but strike each in 48 distinct pulses per revolution as the blades pass in front of each vane. Also, perhaps less distinct but none the less present, are the 14 separate zones of pressure as the blade passes from the influence of one burner to the next.

While no intense audible sound is generated by the passage of the blades through these zones of varying air flow, the effect produced on the blade itself is the same as though it were subjected to a very high level noise. Actually, if it were possible for a person to follow the path traveled by a blade, a high level sound would be experienced whose intensity and frequency would be a direct function of the steady-state pressure variations encountered around the periphery of the nozzle diaphragm.

The Pre-Engine Test

To determine the nature and extent of the turbine blade vibration an engine test with standard parts was made. This test was made possible by utilizing the Allison-developed, high-temperature strain gage. Two blades, diametrically opposite on the wheel, were instrumented with these strain gages mounted on the convex side of the airfoil, at a position where bench testing indicated high vibrational stresses would be found (Fig. 4). The strain gage lead wires passed to the rear of the turbine wheel and forward through the turbine and compressor shafts to a slip-ring assembly mounted on



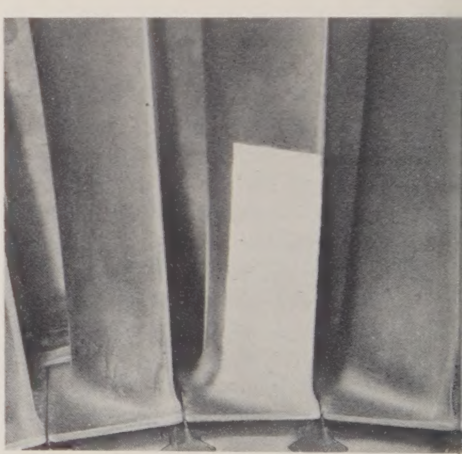


Fig. 4—In order to gather data on turbine blade vibration, an engine test with standard parts was made and high-temperature, Allison-developed strain gages were used. (Left) The strain gages were welded onto the convex side of the airfoil of two blades diametrically opposite each other on the turbine wheel, at the position where bench testing indicated high vibrational stresses would be located (*A*). The strain gage leads enter the turbine wheel shaft (*B*), pass to the rear of the turbine wheel, and forward through the turbine and compressor shafts to a slip-ring assembly mounted on the accessory housing. For the test, the engine was slowly accelerated through its speed range, with short steady-state runs at major resonant speeds of the blades. The strain gage signal sensed the dynamic stresses and the vibrational frequencies. (Above) This is a close-up view of a turbine blade on which a high-temperature strain gage has been attached with special ceramic cement.

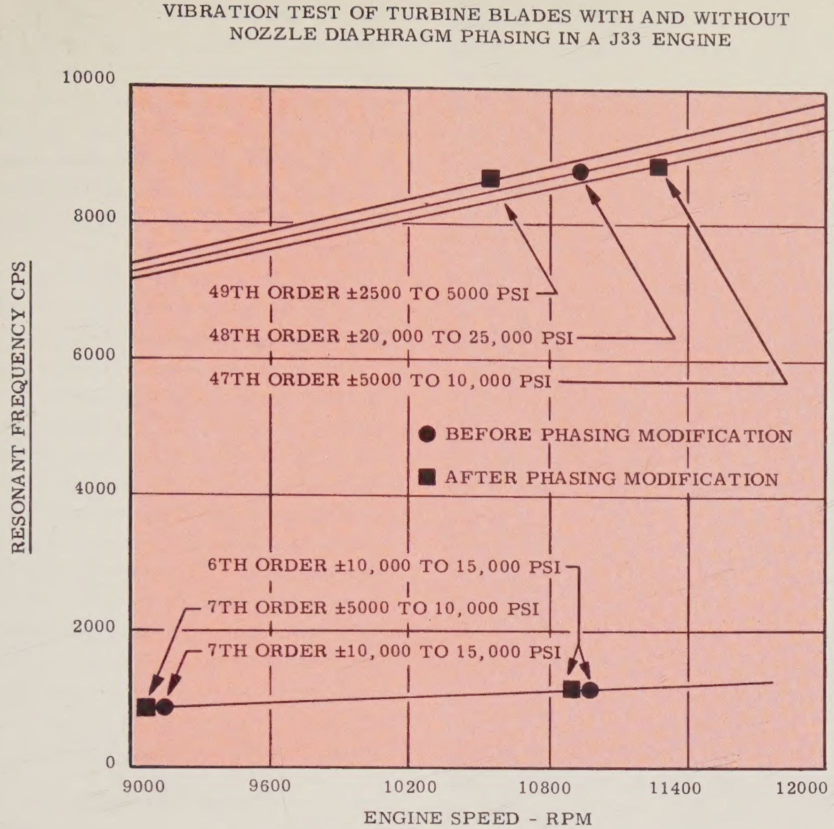


Fig. 5—This graph was set up using calculations from the high-temperature strain gages cemented to the turbine blades in the engine test. These data are concerned with those speeds around the take-off speed (11,800 rpm) and cruising speed (11,000 rpm). Each data point is identified by an excitation *order number* which is equal to the vibration frequency (given in cycles per second) divided by the number of revolutions per second of the turbine. The 48th order which is the most prominent with the unphased diaphragm (±20,000 psi to ±25,000 psi) presents a serious problem as it represents only that stress due to vibration and does not include steady-state loading or centrifugally produced, thermal, or residual stresses. The phased diaphragm completely eliminated the 48th order, introducing much reduced stresses at the 47th order (±5,000 psi to ±10,000 psi) and the 49th order (±2,500 psi to ±5,000 psi).

BENCH TEST FREQUENCY DATA

TURBINE BLADE FREQUENCIES (cps)		
BENCH TESTING		ENGINE TEST
As Measured at 70°F	Estimated at 1300°F	1300°F-1500°F
12190	10700	
9800	8600	8800
8960	7800	
6380	5600	
5746	5060	
5050	4450	4550
4080	3600	3650
3945	3480	
3605	3180	
1820	1600	1670
1107	975	1000

Table I—These bench test frequency data taken at room temperature appear to be widely variant from those frequencies determined in the engine test. However, when these values are corrected—taking into consideration the lower turbine blade modulus at the 1,400° F to 1,500° F temperature range and the effect of the centrifugal forces on the blade during rotation—they serve to identify engine vibrations as natural frequency resonance.

the accessory housing. The engine was slowly accelerated through its speed range, pausing for a short steady-state run at major resonant speeds of the blades. The strain gage signal, which sensed the dynamic stresses and the vibrational frequencies, was amplified and photographed by means of a recording oscillograph.

From the photographic record, calculations were made of engine speeds, vibration frequencies, and accompanying stresses. Fig. 5 presents these data around the cruising and take-off speeds of the engine. (Take-off is at 11,800 rpm and cruising speed at 11,000 rpm.) Maximum dynamic stresses were recorded in excess of ±20,000 psi. This represents a very formidable stressing inasmuch as it includes only that due to vibration and does not include steady-state loading or centrifugally produced, thermal, or residual stresses.

Each resonant condition is identified not only by its frequency in cycles per second, its stress range in pounds per square inch, and its engine speed in revolutions per minute, but also by an excitation order number. The *order number* is equal to the vibration frequency in cycles per second divided by the number of revolutions per second of the turbine. It indicates the vibrations per revolution and presumably is equal to the excitation pulses per revolution, or some integral multiple thereof. In this test the 48th order was by far the most prominent, with the maximum dynamic stress of ±20,000 psi to ±25,000 psi. No significant 14th order, due to burner passage frequency excitation, was present.

Thus, the preliminary test under standard conditions clearly associates the excitation with the vane passage frequency and its attendant acoustical wave pulsations.

Resonant Condition Established

The peaking characteristic of the stress values at certain speeds, with low stress values between, indicates that the peak points represent resonant conditions between sound-wave excitation and a natutral mode of the blade. To verify as completely as possible that these are resonant vibrations rather than forced non-resonant ones, a bench frequency and mode survey of the blades was undertaken. In determining the natural frequencies of the blades standard bench vibration techniques were used. The blades were solidly base-clamped—simulating the rigidity existing during operation—and excited electromagnetically. (Small steel strips 0.005 in. by 0.25 in. by 0.75 in. were cemented to the blades so that they would respond to such excitation.) Amplitudes were measured and stresses at many points on the blade were surveyed by strain gage instrumentation. Vibrational resonances were identified in modes of bending and torsion. Table I lists the findings, along with engine-encountered frequencies. At first glance, the bench test frequencies taken at room temperature are seen to be considerably different from those dynamically detected. However, when corrections due to the lowering of the blade

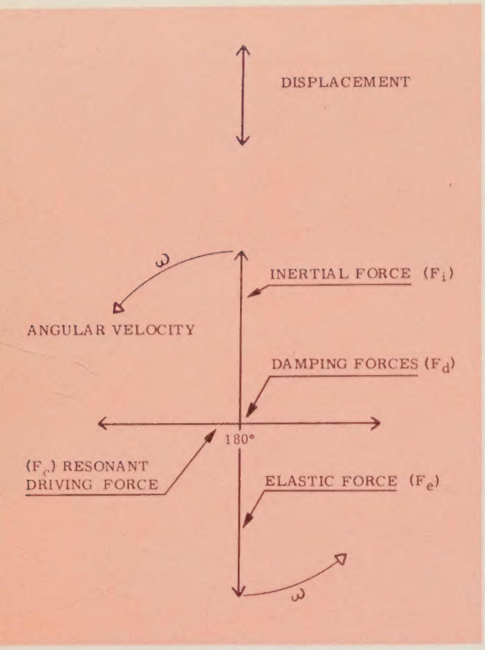


Fig. 6—In vibration analyses, the forces involved are considered as vectors rotating at an angular velocity $\omega = 2\pi f$, where f is the frequency. The forces—at resonance—are represented by vectors with a 90° separation. Under all conditions, if equilibrium (both dynamic and static) is to be maintained, the vector sum of these forces must be zero. Under steady-state resonance, the driving force F_c is equal and opposite to the damping force F_d. When the driving force is shifted 180° by phasing, it is in phase with the damping forces inherent in the system and the driving force then becomes a dynamic damping force. The combined damping forces increase the vibrational energy dissipation and decrease the amplitude and stress.

elasticity modulus at the 1,400° F to 1,500° F operating temperature range are made, together with elastic stiffening corrections due to the centrifugal forces on the blade during rotation, fair agreement between dynamic and static testing frequencies is reached. Because of this agreement of frequencies between dynamic and static conditions, the test served to verify the dynamic vibrations as representing a resonant condition between excitation of vane passage frequency and natural vibrational modes of the blade, with the most severe condition definitely established as that of the 48th order.

Proposed Modification of Design

Many approaches are normal procedure in the reduction or prevention of resonant excitation. But in this case, a proposal to utilize knowledge of reinforcement and interference phenomena of sound waves, when in and out of phase, was accepted as the manner of attack.

It was proposed to break up the regularity of the nozzle vane arrangement in the diaphragm in such a way that during one-half of its revolution a blade would receive wave energy pulses out of phase by 180° from those in the other half. One group of 22 nozzle vanes was spaced at the usual separation followed by two more at three-fourths normal spacing. These closer spaced ones, having shifted the relative spacing by one-half space (180° phase shift), were followed by 23 nozzles at normal spacing, and the circle completed by two more at three-fourths spacing. Thus, two phasing steps of 180° were incorporated nearly diametrically opposite, taking place during the passage of the two closer spaced vanes. This configuration results in a total of 49 vanes in the diaphragm as contrasted to the original 48 (Fig. 3).

It was reasoned that resonant vibrations of the blade would experience reinforcements from the vane passage excitation for one-half revolution and then—because of the 180° phase shift interference during the remainder of the revolution—the overall result would be a much reduced blade vibrational amplitude and lower accompanying stress. Engineering ingenuity was proposing to utilize the selfsame factors which were producing the vibration as the mechanism for securing its reduction.

Dynamic Damping

Standard procedure in vibration analysis is to consider the forces involved as rotating vectors, rotating at an angular velocity $\omega = 2\pi f$ where f is the frequency (Fig. 6). The various forces involved are:

F_e = elastic forces of the blade

F_i = inertial reaction forces ($F = MA$)

F_d = inherent damping forces of the system

F_c = resonant driving force.

At resonance, the forces are represented by vectors with 90° separation. The inertial reaction force is in phase with the displacement. The elastic force is 180° out of phase with it. The driving force leads the displacement by 90° and the damping force lags by 90°.

Under all conditions, if equilibrium (dynamic and static) is to be maintained, the vector sum of these forces is zero. Under steady-state resonance the excitation or driving force is equal and opposite to the damping force.

Assume the system to be in a steady state of resonance when suddenly the driving force is shifted by 180°, placing it in phase with the damping forces inherent in the system. Then it too becomes a damping force — a dynamic damping force. The two combined damping forces speed up the dissipation of vibrational energy with a corresponding decrease in amplitude and stress.

The normal damping forces at the stress levels encountered are usually of a low percentage of amplitude decay per cycle. With these normal damping forces and the reversed driving force vector acting together, it is not to be expected that within 24 cycles or less the amplitude could decrease to zero and regain its original high value. Neither could it, if starting from zero amplitude, be expected to build up to its former high values before phase reversal. It would be anticipated in continuous running that the amplitude would rise and fall in half-revolution cycles, varying around amplitude and stress maximum values much less than for the unphased excitation.

Simulated Testing

Before making the proposed change, followed by a confirming engine test, a simulated test was planned. With the conviction that engine excitations stemmed from sound waves, it was felt that a siren would be the best simulated exciter. Because of this similarity and its usefulness as a tool in vibrational analyses a word of explanation of sound generation by a siren is appropriate.

Air jet sounds from continuous and intermittent flow have been analyzed through high speed photography and reported by Barnes and Bellinger. The report states: "When a sonic jet exhausts with pressure greater than the ambient value, the initial widening of the stream is followed by a contraction to a condition approximating those at the exit from which condition it alternately expands and contracts, usually through several cycles until finally breaking up into turbulence."[3] Most of the sound apparently is generated in the vibrating air stream after emission from the siren, and presumably it is the major source of energy transfer when jet excitation is used as a vibration test tool.

In the simulated test the relative motion of nozzle vane and blade was reversed. The nozzle diaphragm, simulated by the siren wheel, rotated while the blades were clamped in a fixed

mounting (Fig. 7). Two siren wheels were utilized. One simulated the normal nozzle diaphragm and burner configuration with 48 equally spaced holes around the periphery and 14 holes equally spaced around a slightly shorter diameter. The phased wheel had 49 holes spaced as previously described for phasing, with the unphased 14 openings remaining unchanged. The siren was driven by a variable speed motor and utilized compressed air. During the simulated tests, siren speeds were recorded as well as strain gage signals from gages attached to the blade as in the engine test. Difficulty was encountered in securing the higher frequency excitations recorded in the engine test and identified by bench testing. It was more convenient to draw conclusions from the lower frequencies which could be more readily excited—hoping that the conclusions would be reasonably valid for the higher frequencies.

Results of Simulated Test

The most significant conclusion from the simulated test utilizing the 1,050 cycles per second blade vibrational mode is that the maximum stresses in the 48th excitation order produced by the unphased siren were ±22,625 psi, while the maximum stresses under the otherwise identical conditions of the phased siren were ±15,500 psi in the 49th order and ±14,200 psi in the 47th order—none in the 48th. Thus, a substantial reduction of some 31 per cent of the maximum stress was achieved. For other frequencies, the reduction ranged from 35 per cent to 50 per cent (Table II).

It had been anticipated that the 96th order might prove dangerously resonant, as the phasing would not be expected to be effective for double the previous frequencies since every second cycle of such a frequency still could be resonantly excited by the phased wheel. No serious stress actually occurred in this order, either before or after phasing.

It is interesting to note that with the phased siren the maximum excitation no longer occurred at the 48th order, but rather at the 47th and 49th orders with stresses of much smaller magnitudes. It has been suggested that these frequencies were beat notes representing the sum and difference of the 48th order and the ever present 1st order previously mentioned.

Further investigation was made with a wheel in which four half-space shifts (180° each) were made instead of the two reported above. This was found to be less effective in reducing stress, but the excitation stress maxima were then shifted to the 50th and 46th orders, effectively exploding the suggested "beat" theory.

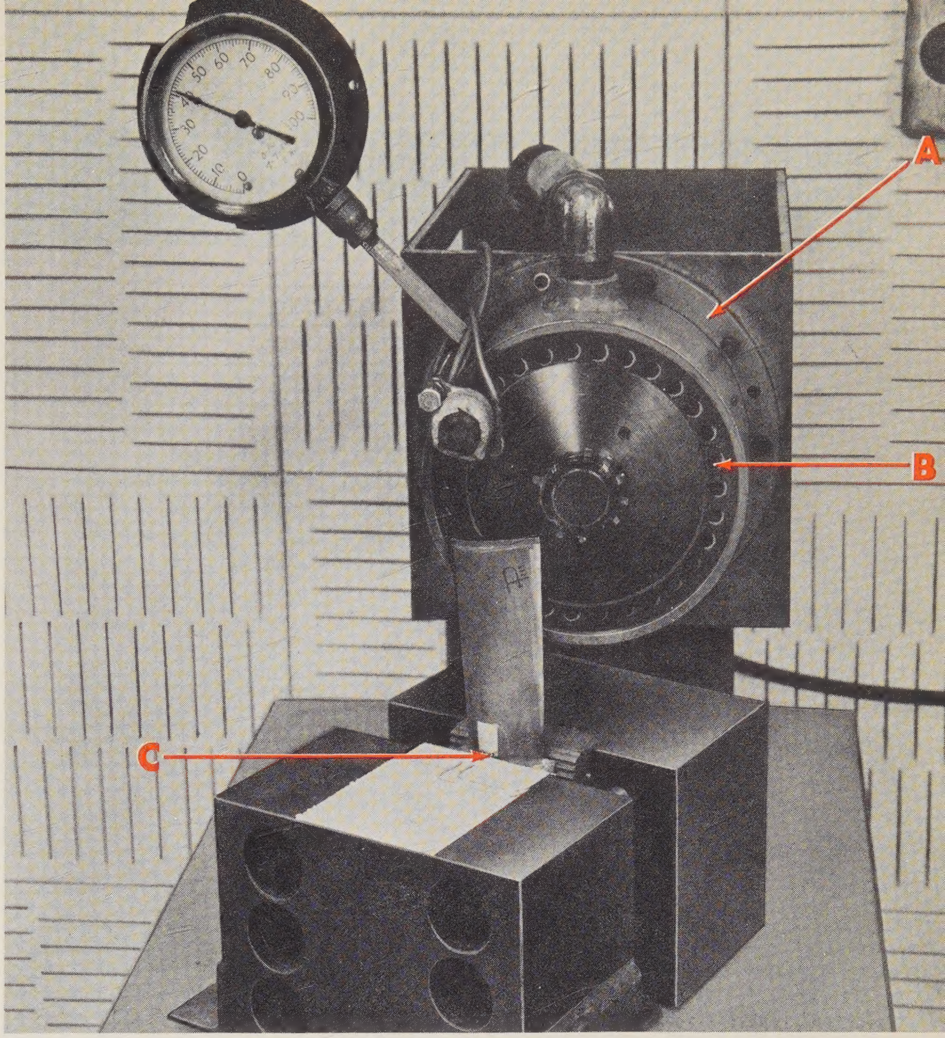


Fig. 7—This laboratory apparatus is used to simulate the pulsating sound waves which strike the turbine blades as they pass the nozzle diaphragm during engine operation. An air siren driven by a variable speed motor (*A*) was used as the engine exciter because of the conviction that engine excitations stemmed from sound waves. *B* shows the revolving disc with holes to provide the desired rate of air pulses; *C* shows the strain gage used to sense stress at the critical points in the vibrating turbine blade. In the simulated test, the relative motion of the vane and blade was reversed; the nozzle diaphragm—simulated by the siren wheel—rotated, while the blades remained stationary. As it was difficult to reach some of the higher frequency excitations recorded in the engine test, engineers had to apply conclusions drawn from the lower frequencies.

A fairly dramatic demonstration of the influence of periodic phase shifting of the excitation was made by exciting a glass tumbler at its fundamental resonant frequency by sound wave bombardment from the unphased siren (Fig. 1). The photograph shows the resultant failure due to vibrational overstressing. When duplication of the demonstration was made under identical conditions but with the phased siren, the failure stress level could not be attained.

Final Engine Testing

Finally, the phased nozzle diaphragm was placed in the engine for testing with the same blades and instrumentation as before, taking similar data with the phased nozzle diaphragm as the only variant. From Fig. 5 the most significant change noted is that the maximum high frequency stress is no longer in the ±20,000-psi to ±25,000-psi class but in the ±5,000-psi to ±10,000-psi class, representing a stress decrease of 50 per cent to 75 per cent.

The maximum stress was no longer in the 48th excitation order, but the original unchanged 6th order value was now the maximum. It must be remembered that the phasing was not primarily expected to be effective at this order. It

SIMULATED SIREN TEST RESULTS

Order No.	±DYNAMIC STRESS (psi) 1050 CPS In-Phase	1050 CPS Out	5203 CPS In-Phase	5203 CPS Out
112	±1520	±1185		
96	±4655	±3875	±1520	±1660
63		±2875		
62	±4300		±1075	±580
61		±2840		
57		±1520		
55		±2000		
53		±3230		
51		±5650		±678
49		**±15500**		**±2710**
48	**±22625**		**±5235**	
47		±14230		±3100
45		±4295		±1180
34	±3230	±1940	±905	
28	±1875			
14	±10750	±11625		

Table II—This table lists the results of the simulated siren test to determine the effect of out-of-phase conditions in breaking up vibrations in the Allison J33 turbine blades. The in-phase siren rotor has 48 equally spaced slots on the outer diameter. The out-of-phase siren rotor has 49 slots (23 slots at normal spacing, two slots at three-fourths spacing, 22 at normal spacing, and two at three-fourths spacing.) Both siren rotors have 14 equally spaced holes on the small diameter. The phasing configuration caused a shift from high stresses in the 48th order (in the unphased siren ±22,625 psi for the 1,050-cps blade vibrational mode) to low stresses in the 49th and 47th orders (in phased siren ±15,500 psi and ±14,200 psi, respectively.) Note there is no stress in the 48th order with the phased siren. The result is a 31 per cent reduction from the maximum stress.

was planned to break up the excessive vibration of the 48th order. This it did. The 48th order was eliminated and replaced by 49th and 47th orders, both having stresses of less than ±10,000 psi. This was more than a 50 per cent reduction in the region intended.

Further tests in the use of phased nozzle diaphragms have resulted in a substantial decrease in turbine blade failures. It has since been adopted as a standard engine part and the principle of phasing may be extended to many similar uses.

Conclusion

The jet aircraft industry is faced with sound suppression and control at higher intensity levels than ever before encountered. For the first time in man-made machines, sound becomes a significant source of mechanical fatigue damage and stress, over and above its nuisance character. Acoustical radiation becomes the seat of losses of formidable amounts of energy from supersonic propellers and the jet stream.

With such high sound levels, component parts of the engine become acoustically coupled in such a way as to set up dangerously high stress levels in resonant vibration. Principles of sound transmission, interference, and reinforcement—as demonstrated in the above development—can and must be utilized in coping with this increasingly serious sound problem in the aircraft industry. Such acoustical phenomena may be utilized as tools, as in the case of siren excitation, as well as counter control measures. Knowledge of sound is no longer an unnecessary appendage in engineering education but a basic must.

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Instruments Are the Tools of Research

By ALBERT F. WELCH

General Motors

Research Staff

Add instrumentation to the questing mind and research may proceed

Advances on every avenue of scientific development and application have placed greater emphasis on instrument sensitivity, accuracy, speed, and reliability. Such developments have resulted in vastly superior but infinitely more complex instrumentation which requires special attention. The General Motors Research Staff has set up an instrument service section which assists in instrumentation problems. Even though more than ten thousand instruments are available, frequently needs arise where equipment must be modified or new instruments designed and built. Day-to-day operations require solving such problems as obtaining the number of revolutions per minute of an internal shaft when a mechanical connection cannot be made.

MAN HAS within his body an amazing assortment of instrumentation. In the case of such physiological conditions as body temperature and breathing rate, an excellent automatic control system operates from numerous complex inputs to provide precise and proper adjustment to environment. In addition, man is blessed with indicating systems which are broadly classed as the senses of sight, smell, touch, hearing, and taste. These are the only avenues through which raw information reaches the mind for processing. Because these indicating systems have shortcomings, such as delicacy of the transducer, inability to record results accurately, and difficulty in excluding subjective biasing, the unaided senses prove inadequate for many investigations. Instruments are simply extensions of the senses which tend to overcome their shortcomings. As a result, instruments are always a means and never an end in themselves. Only when the senses are unable to supply sufficient information are instruments used. In modern research there are very few problems remaining which will yield to application of the unaided senses. Hence, instrumentation has become increasingly necessary.

A most important advantage of instruments is their ability to convert characteristics of a phenomenon into numbers which are universally understood, since they are based upon accepted standards. Even where the senses prove adequate for solving a particular problem it is often well to make sufficient measurements to allow precise description. Reducing the important parameters to numbers is the only positive way to assure that the test can be repeated.

Advances in every phase of scientific development and application have placed greater emphasis on instrument sensitivity, accuracy, speed, and reliability. Where areas have been quite thoroughly explored, much closer control and scrutiny of variables are required if development is to be continued. The relatively virgin territory remaining is in areas such as nuclear research where even a beginning is based upon extremely complex instrumentation.

Competition and a natural desire to operate more efficiently have resulted in the development of superior production equipment varying all the way from the integrated continuous flow chemical plant to the improved punch press. These developments have placed an extreme responsibility on the instrument engineer for designs to control adequately product quality, to promote personnel safety, and to protect the greatly increased equipment investment. Such developments as these have resulted in vastly superior but infinitely more complex instrumentation (Fig. 1).

Because of the increasing use and complexity of instrumentation, many organizations have set up specialized groups for the specific purpose of providing instrumentation assistance. A typical group of this kind is the Instrument Section of the General Motors Research Staff. Since this Section assists in practically every Research Staff project, its personnel are characterized by a high degree of specialized talents.

Three Working Groups Join Forces

The Instrument Section is composed of three groups: Dynamometer, Construction, and Service. Each was established

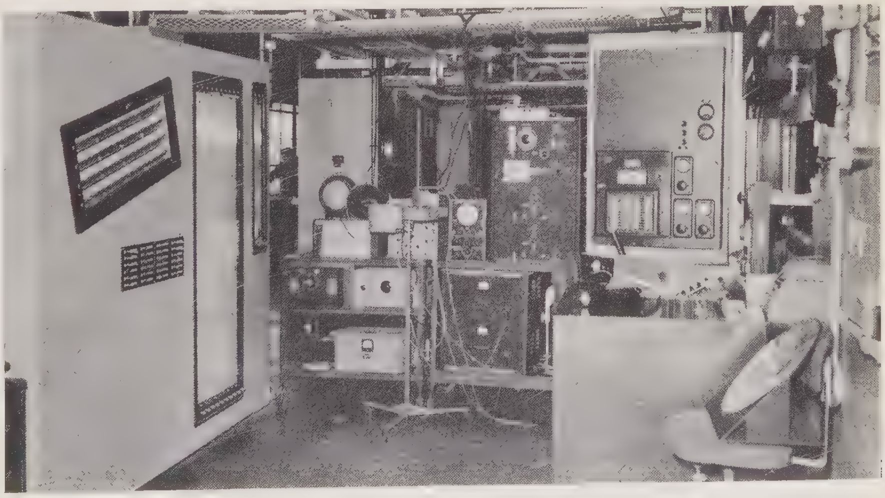


Fig. 1—Shown here is a test-cell control room containing typical instrumentation for investigating surge in gas turbine compressors. The test cell, not visible, is to the right.

Fig. 2—General view of one corner of the Instrument Laboratory where frequent calibration and testing are performed on instruments to insure their accuracy.

to fulfill instrumentation requirements in a particular area and each has distinct responsibilities. Nevertheless, a large part of the assistance offered Research Staff's personnel is provided through cooperative efforts.

The Dynamometer Group is responsible for the proper performance of the numerous automotive and turbine dynamometers, ranging from 1½ hp to 500 hp, and other controlled rotating equipment such as rubber mills, magnetic clutches, and thyratron-controlled lathes. Since torque and speed are the measurements obtainable from a dynamometer, this Group also is responsible for torque- and speed-measuring instruments.

In addition to performing normal service work, basic dynamometer performance characteristics are investigated. Typical is an investigation on the effects of vibration and temperature on torque weighing systems.

The Construction Group is primarily concerned with the making of new instruments which are not commercially available. Major modifications of existing instruments also are performed by this Group. Typical recent projects involving design, construction, and testing include a precision automatic voltage control which maintains voltage constant to better than 0.001 v (0.2 per cent of full scale) from no load to full load, a differential temperature controller to maintain close control of the difference in temperature between an oil bath and room temperature, and a multi-point thermocouple scanner for shutting down a bearing-test machine should any point go over a preset maximum temperature.

The Service Group services all Research Staff instrumentation. Application, calibration, and repair of equipment are major tasks and some time also is spent on minor modifications and productive maintenance of installed instruments. All work is done in close cooperation with operating departments. The Service Group also undertakes or assists in numerous instrumentation investigations. Typical examples are: development of a fuel metering system to measure flow of fuel delivered at the extremely high flow rates required by gas turbine engines and design of a dipstick-type thermocouple for measuring molten metal temperatures.

Ten Thousand Instruments at Work

The Instrument Section coordinates use of 10,000 instruments of every type and description—electric, hydraulic, mechanical, pneumatic, and combinations of these. They range from quartz fibre electrometers to 500-hp dynamometers. A large inventory of equipment, however, is not necessarily indicative of rapid technological advancement. A basic understanding of pertinent variables and an ingenious application of available instruments are paramount.

All instruments are made available to Research Staff personnel from the Instrument Section on a loan basis. The magnitude of this interchange is indicated by the fact that approximately 33,000 requests were received in 1954 with the loan time ranging from a few minutes to several months. Most of these instruments must be calibrated and tested frequently to insure accuracy (Fig. 2). This work is done mainly in the central Instrument Laboratory.

Typical Instrumentation Problems

Mutual orientation of the instrument engineer and the project engineer is essential for the solution of most technical problems. The instrument engineer knows his specialty and has a general knowledge of allied fields. To make most effective use of his measurements and control knowledge, however, the variables involved need to be explained by the project engineer.

It has been found that the solution to most instrumentation problems generally falls into four categories. These are:

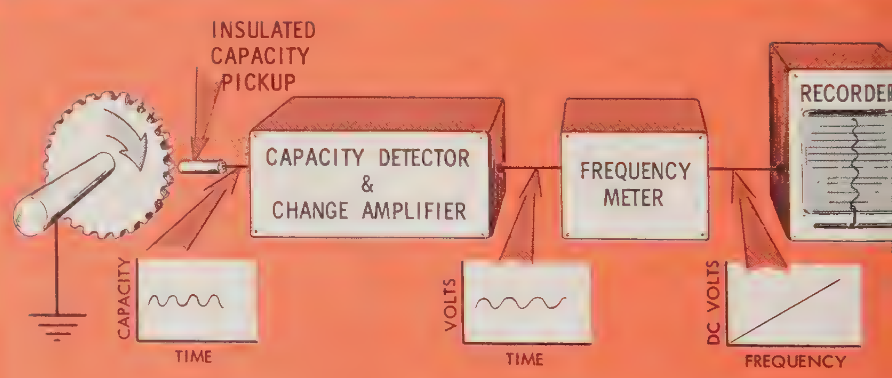
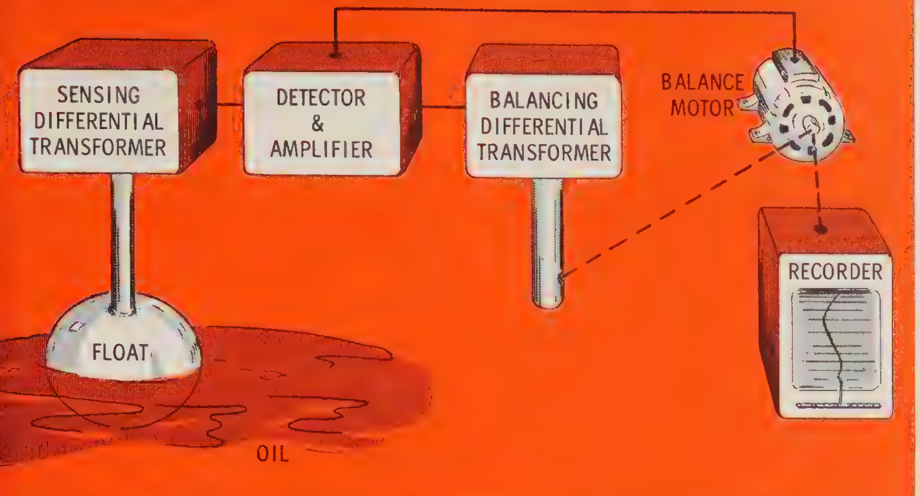


Fig. 3—The measurement of rotational speed of a gas turbine shaft without touching or loading t shaft is obtained by using a capacity pickup. Changes in capacity, as the gear rotates, develop a pulsati voltage signal which is fed to the frequency meter where a d-c voltage is developed which is proportion to the capacity-change frequency. A recording oscillograph indicates speed of the rotating gear.



g. 4—The measuring of the oil level in an internal combustion engine's oil pan is carried out by a ferential transformer system. The motion of the float changes the core position in the sensing trans-rmer and produces a differential voltage at the detector. The detector actuates the balance motor to ive the slug of the balance transformer to the same relative position. The recorder pen also moves cordingly.

(a) Use of presently owned instrumentation, as is
(b) Modification of above to meet special conditions
(c) Purchase of commercially available equipment
(d) Design and construction, if not otherwise available.

Use of Presently Owned Instrumentation

Problem: Measure the rotational speed of a gas turbine shaft when no output shaft is available.

A small automotive gas turbine was designed by the Research Staff's Gas Turbine Department and used in the first American-built gas-turbine powered automobile. Of the twin-spool-turbine type, this engine has the first turbine wheel mounted on the same shaft as the compressor wheel. The first turbine wheel extracts only enough energy from the gas stream to drive the compressor. Since this section serves only to generate pressurized hot gases it is called the gasifier section. Energy remaining in the hot gas is extracted by the second or power turbine wheel which is coupled through a transmission to the rear wheels of the car.

The design is such that a conventional speed-measuring pickup could not be coupled to the power turbine shaft. Some method not requiring a direct coupling had to be devised.

Solution: A capacitance-sensitive transducer was used to pick up pulses from a gear on the gasifier shaft.

For some time the Research Staff has made extensive use of capacitance-change-detecting electronic equipment. This equipment may be compared to a public address system using a condenser microphone. Changes of the input capacity result in corresponding changes in the output voltage.

A small electrically insulated probe was mounted through the case opposite a gear on the shaft (Fig. 3). The probe served as the fixed condenser plate. The rotating gear teeth varied the spacing to produce the desired capacity changes. One pulse per tooth was generated with a resulting output frequency directly proportional to shaft speed. This signal was fed into a frequency meter which converted the pulses into a d-c signal proportional to shaft speed. This signal, in turn, was transferred to a recording oscillograph.

All the instruments were available and only the pickup probe required special attention.

Modification of Presently Owned Instruments

Problem: Record the sump oil level in an internal combustion engine.

In a recent project concerning oil consumption, the Research Staff's Automotive Engines Department needed an accurate means of measuring and recording the oil level in an engine oil pan. In this case, time was an important consideration.

Solution: A strip-chart recording potentiometer was available. While the measuring circuit was inoperative and obsolete, the chart drive mechanism was in good condition. The potentiometer cir-

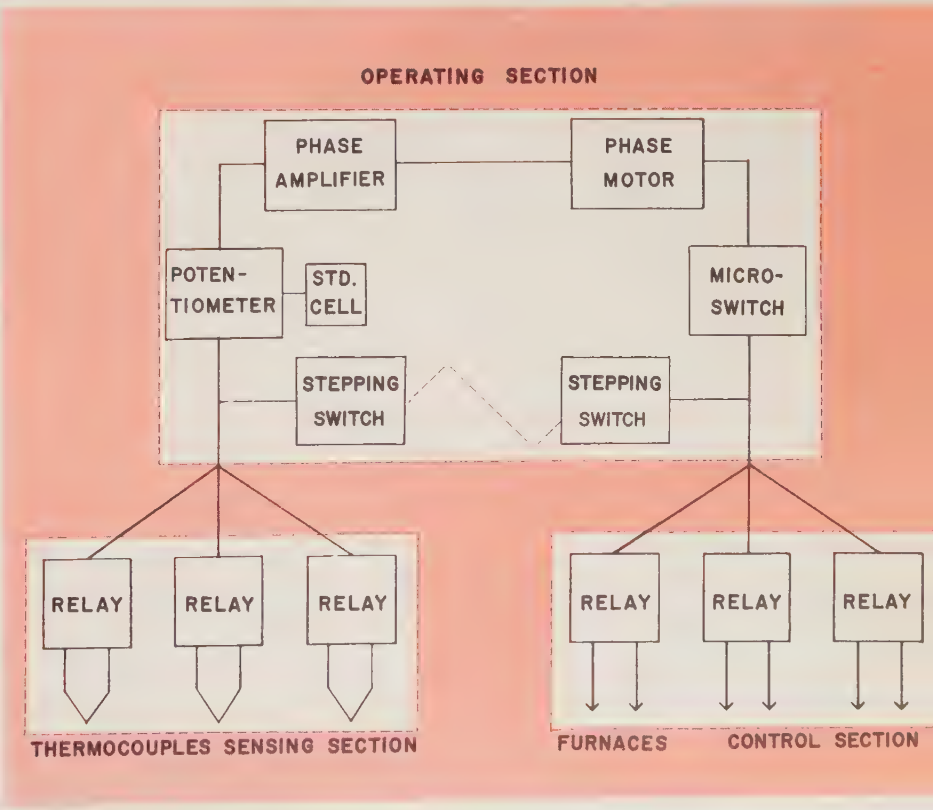


Fig. 5—A multi-point thermocouple scanner layout is used for controlling and recording the temperatures of 20 creep-test furnaces. The operating section is common to all individual sensing thermocouples and their associated control relays.

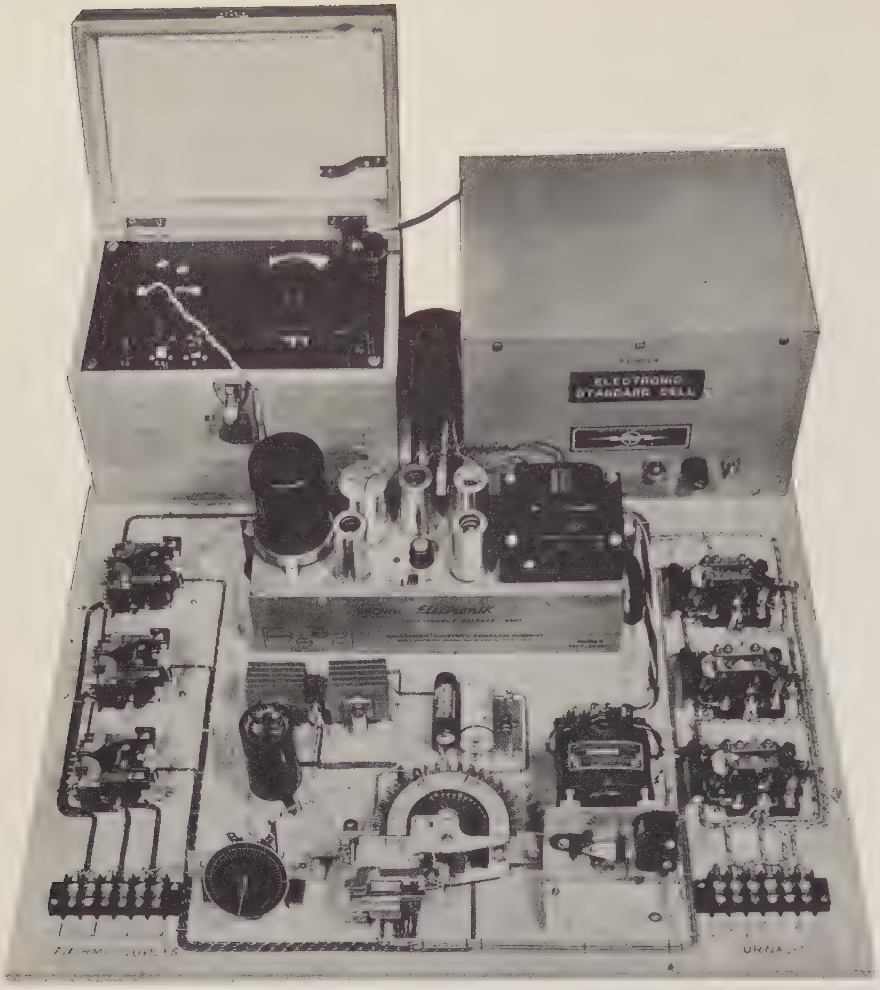


Fig. 6—A three-point "breadboard," multi-point, thermocouple scanner-controller was built to determine proper scanning rate in creep-test furnace work. Such experimental setups are indispensable in establishing practicableness of new applications.

cuit was removed and a commercially available servo follow-up system substituted. This system utilized a differential transformer bridge (Fig. 4). The sensing transformer was located in the oil pan with its movable core actuated by a float. The balance transformer was located in the recorder with the associated balancing mechanism also driving the ink pen. Full scale travel was 0.1 in. with accuracy of 0.001 in.

Purchase of Commercially Available Equipment

An important task of the instrument engineer is to keep abreast of information on new instrumentation. Requests for new instruments are usually initiated by engineers in the various departments of the Research Staff with the cooperation of the Instrument Section in establishing specifications as well as determining applications.

Problem: Record and control the temperature of 20 creep-test furnaces.

The turbine buckets of a gas turbine engine undergo extremely severe conditions of temperature and stress. To increase thermal efficiency, engine development engineers use design temperatures as high as metallurgical characteristics allow. Because of high rotational speeds, centrifugal forces produce high stresses.

Under these conditions a phenomenon known as "creep" occurs in the buckets. The material gradually deforms plastically, even though the stress is below the elastic limit for the temperature. This can result in permanent elongation—extremely dangerous in the small clearances maintained in gas turbine engines.

In the development of bucket alloys, resistance to creep is obviously an important characteristic. Since an aircraft in flight is hardly the place for tests of this nature, a standard testing procedure has been developed. A standardized bar of the alloy is heated under stress in a muffle furnace. The elongation is recorded while the stress and temperature are maintained constant.

Since developments in this area are proceeding rapidly and because many tests are needed to determine statistically adequate values, 20 creep test units have been set up. Individual recording controllers would be extremely expensive as well as space consuming.

Solution: Scanning, multi-point recorder-controllers are commercially available. Such devices will sense the temperature of one point at a time and apply proper ON-OFF control action to the particular furnace. The next point is then sensed (Fig. 5). Power remains in the ON or OFF position until the cycle is completed and the scanner returns to the particular point. To investigate the possibilities of such control, a three-point thermocouple scanner was built in "breadboard" style (Fig. 6). Extensive tests were run to determine proper scanning rate and general suitability. Results were excellent. A commercially available 20-point unit was then purchased. Performance to date has been up to expectations.

Design and Construction, if Not Otherwise Available

Problem: Indicate over-temperature condition at any one of a number of points in an engine.

Because of the extreme rate of heat release taking place during combustion in an engine, there is always present a problem in handling this heat. Any one of a number of malfunctions can result in overheating and damage. In addition, loss of lubrication in a bearing or any unusual friction can generate sufficient heat to cause failure.

Early detection of this heating is often sufficient to allow preventative action. In the past, engineers measured oil and coolant temperatures only. These did not detect local failures which could cause damage without the generation of an appreciable amount of heat. With present-day engines, especially gas turbines, the problem has become so critical that it is customary to install a large number of sensing elements, usually thermocouples, in critical locations. However, monitoring all of these points is difficult for the following reasons:

- Individual indicators would be expensive and take too much space

• Using one indicator and a manually operated switch would require undue time
• Due to being in different locations, widely different temperatures would indicate trouble. The operator would have to key in each point with some sort of chart.

Solution: The obvious solution was a multi-point scanning indicator with individual set points. Since a suitable unit was not available one was designed and constructed (Fig. 7). With this unit the danger level for each point may be set. If that temperature is exceeded a warning light glows and corrective action can be taken. The scanning rate is relatively high (18 points in 10 sec) to cover cases of rapid heating.

In some difficult locations only one thermocouple can be located. It may be necessary to record the temperature of this couple continuously and, at the same time, check it for over-temperature. To prevent interaction of the two measuring systems it was necessary to transfer the thermocouple completely from one system input to the other. This was accomplished by using a double-pole, double-throw relay for each thermocouple. Scanning speed is so rapid that the couple is transferred from the recorder, checked, and returned before the recorder pen can move, resulting in an apparently continuous record.

Instrumentation for a Typical Project

Each of the cited examples resulted in a solution to a specific instrument problem. Most projects involve a number of problems with any of the methods being used to obtain specific measurements.

The Gas Turbine Department initiated an investigation of surge in gas turbine compressors. This is an extremely difficult area from an instrumentation viewpoint and the equipment developed was extensive and complex (Fig. 1). Speed and temperature measurements were easily provided by available instruments (already owned or commercial). The detection of gas velocity changes during surge presented a particularly difficult problem. This was solved by designing and constructing a hot-wire, constant-current thermal anemometer. A commercial servo follow-up actuator is used to position the hot-wire probe. This actuator was extensively modified to provide additional modes of operation and to allow more exact calibration. Thus, all four methods of obtaining equipment have been used just in setting up this one project.

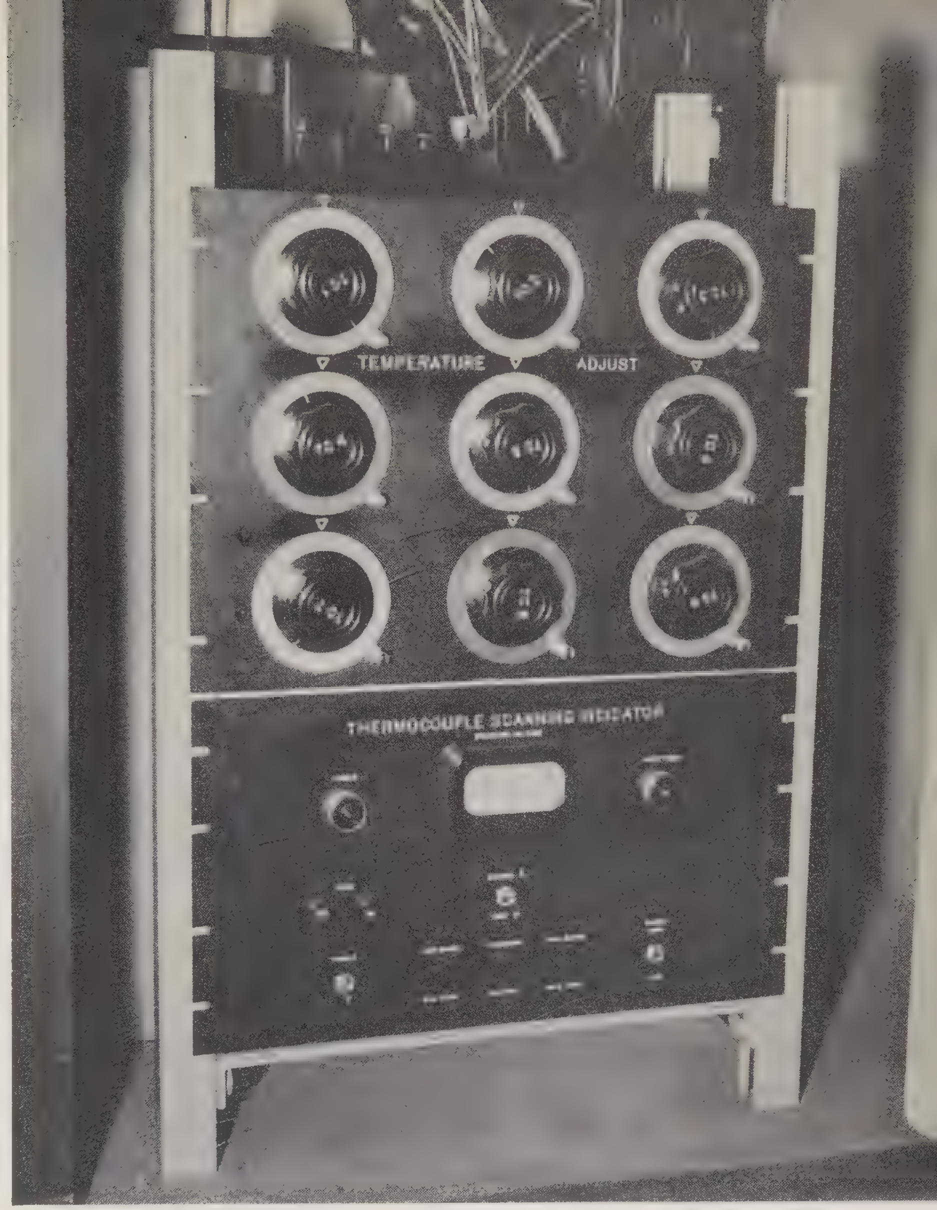


Fig. 7—A thermocouple-scanning indicator is used to indicate over-temperature conditions at any one of a number of points in an engine. The lower chassis contains the components common to all points. The upper chassis contains nine individual set point dials and relays. Another nine-point chassis utilizing the common operating chassis can be added.

After the project got under way, engineers were faced with the task of absorbing and understanding the information which the initially installed instruments could offer. When they began to assimilate the data provided, they found that further information requiring even more instrumentation was necessary. This turn of events demonstrates quite aptly why the instrumentation field is a growing one. The information which it is asked to provide seems to have no limits as development projects continue to contribute toward new and better consumer products.

Summary

Instrumentation is essentially a service field in which the participants are constantly challenged with problems of satisfying the measurement requirements of almost every field of research and engineering. Observed phenomena are often of little value in research and developmental work unless they can be measured. Man's innate senses, in most cases, are incapable of making the required measurements because of their relative insensitivity and because they are prone to subjectivity. To measure requires instrumentation, an area of technology which never ceases to find avenues for service.

Development of an Improved Method for Cupola Charging to Meet Increased Production Requirements

By HARRY G. McCALLUM
Pontiac
Motor
Division

New methods permit increased production with existing cupolas

An important operation related to efficient iron casting production is the melting of pig iron and other metallic raw materials in a cupola. The rate at which the metallic materials and the coke and limestone necessary for the melting operation are introduced—or *charged*—into the cupola is geared to casting production requirements. Recently, the Cupola Department of Pontiac Motor Division's foundry was faced with the problem of increasing the output of molten iron to meet an increased demand for iron castings. The addition of more cupolas was undesirable because of the physical layout of the Department's facilities. The most likely way to meet the demand for increased melting rates was to develop a new method for cupola charging—a method which would be economically feasible and retain much of the existing equipment and facilities.

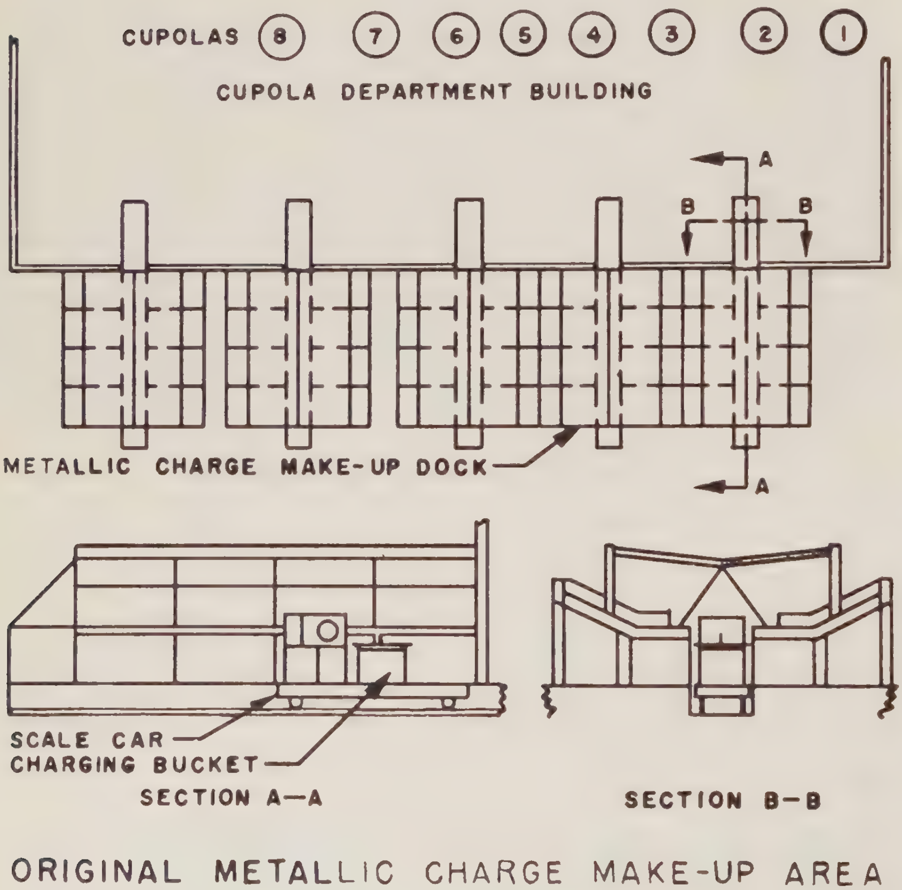


Fig. 1—The metallic charge make-up operations previously were performed on five charge make-up "docks" located on a first-floor level outside of the Cupola Department building. Each dock had eight bins which contained materials required to make either hard- or soft-iron charges for the eight cupolas. The metallic charge was made up in a charging bucket mounted on a scale car which ran on rails between the loading platforms of each dock. The charging bucket was stationed opposite each bin and the correct weight of material required was loaded. After the complete charge had been made up, the scale car moved the bucket inside the building for subsequent charging.

Foundry technology is based upon many individual operations and processes which contribute to a final end product—the finished casting. One such contributing operation concerns the melting of pig iron, scrap, and other materials in a cupola to provide a ready source of molten metal for casting.

The metallic materials and nonmetallic materials, such as pig iron, steel, remelt, coke, and limestone, which enter a cupola during an operational run are known as the *charge* and the act of supplying the materials is known as *charging*. The operation associated with the preparation of charge materials is referred to as *charge make-up*. The equipment used for charge make-up and charging constitutes a *cupola charging system*.

There are two basic requirements a cupola charging system must satisfy—production requirements and metallurgical requirements. The production requirements are concerned primarily with the rate of charge make-up and charging. The quantity of cupola charges required for an operational run is determined by the cupola melting rate and, under normal operating conditions, the cupola metallic-charge charging rate is equal, in tons, to the cupola melting rate. Any fluctuation in the charging rate will produce similar fluctuations in the melting rate.

The metallurgical requirements of a cupola charging system are concerned principally with the weight accuracy of charges. The weight of each charge material is specified by the foundry's Metallurgical Department and it is highly important that the specified weight be accurate. The weight of each metallic-charge material must be exact in order to obtain molten iron of desired chemical and metallurgical composition. Likewise,

each coke and limestone charge must be exact in weight to produce molten iron at the desired melting rate, temperature, and slag fluidity.

Another metallurgical requirement pertains to the cleanliness of metallic charges. As the amount of foreign material increases, such as sand which adheres to gates, runners, and sprues of scrap castings, more slag is formed in the cupola. This requires more limestone to maintain desired slag fluidity and to neutralize the acidity of the sand. An efficient cupola charging system must be capable of producing metallic charges which contain less than 1 per cent by weight of foreign material.

Recently, the Cupola Department of Pontiac Motor Division's foundry faced the problem of increasing the output of molten iron to meet an increase in iron casting production. This increase would require an overall cupola melting demand of approximately ninety tons of molten metal per hour for the eight molding lines. Calculations showed that to meet the increased melting demand, each cupola had to be charged with both a metallic charge and a coke and limestone charge in a total maximum time of 2.5 min.

The existing cupola charging system, which had satisfied melting demand requirements for approximately fourteen years, was not capable of fulfilling the new charging rate demands. It became necessary, therefore, to develop an improved cupola charging system—a system which would satisfy the new production and attendant metallurgical requirements, would be flexible enough in design to meet any future requirements, would retain as much of the present system's equipment as possible, and would be within economic reason.

Existing Cupola Department Facilities

The first step in developing an improved charging system was to survey the Cupola Department's facilities. It was decided at the start that no addition would be made to the number of cupolas then in existence and no expansion made to the building which housed the Department. The restrictive space limitations regarding the Department's location in respect to the foundry's location and facilities made this decision mandatory.

The Cupola Department is equipped with six 102-in. diameter cupolas, refractory lined down to a 66-in. diameter melting zone, and two 108-in. diameter cupolas, refractory lined down to a 75-in. diameter melting zone. The eight cupolas, which produce hard and soft iron, are designed for rear slagging and are tapped directly into bull ladle transfer cranes. Holding ladles cannot be used due to space limitations. It is, therefore, highly important to maintain correct charge weights of the various components.

At the time of the survey, two 102-in. cupolas and one 108-in. cupola were in operation at the same time. While these were in operation, two 102-in. cupolas and the other 108-in. cupola were being lined and prepared for the following day's operation. The cupolas were grouped in pairs, such as 1-2, 3-4, 5-6, and 7-8. Cupolas 1, 3, and 7 were operated one day and cupolas 2, 4, and 8 the following day. Cupolas 5 and 6 were kept in reserve.

The building which houses the eight cupolas is an integral part of the foundry building and consists of three floors. At the time of the survey the cupola slagging, tapping, and control operations were performed on the first floor. Also located on this floor were scale cars and transfer trucks used in conjunction with weighing the metallic charges and transferring them to a central location for subsequent charging into the cupolas. Located outside the building, on the first floor level, was the metallic charge make-up area. The second floor of the building contained five centrifugal-type cupola blowers. On the third floor were located four coke and limestone weigh hoppers, eight 3-ton, rail-mounted, cupola charging cranes which handled the coke and limestone and metallic material charging buckets, and coke and limestone charge-transfer trucks.

Adjacent to the building housing the Cupola Department was a metallic charge raw-material storage yard. Located within the storage-yard area were bins for storing the cupola metallic charge materials: KCN (potassium cyanide) pig iron, foundry pig iron, malleable pig iron, silvery pig iron, cast-iron and steel scrap, steel bales, and cast-iron and steel briquettes. (The briquettes are made from cast-iron borings and steel chips by equipment housed in a separate building located in the storage-yard area.) The metallic charge materials were transferred from the bins to the charge make-up area by three 10-ton, bridge-type yard cranes.

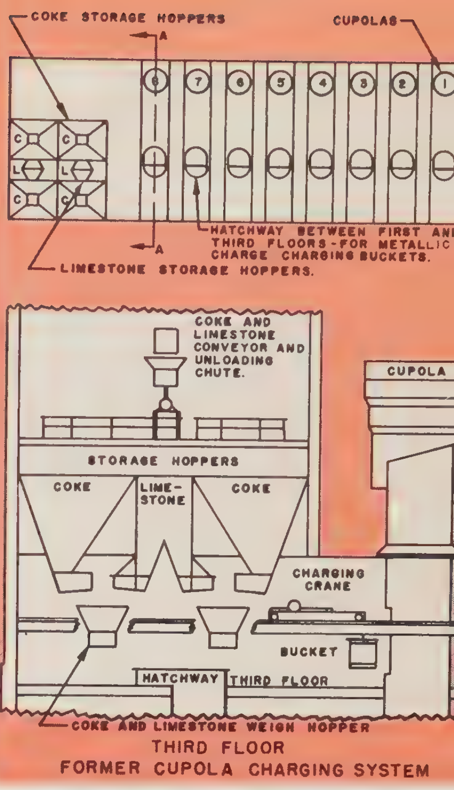


Fig. 2—In the former cupola charging system, a conveyor belt transferred coke and limestone from a storage-yard pit-type hopper to individual storage hoppers positioned above the third floor (charging floor). The coke and limestone, combined as a single charge, then were transferred individually to weigh hoppers where the correct amount of each material necessary for a charge was weighed automatically. The materials were next dumped into a charging bucket. A transfer truck (not shown) then moved the bucket to a charging crane pick-up point for subsequent charging into the cupola. In the improved cupola charging system, only the coke and limestone storage hoppers and the method for conveying these materials from the storage yard have been retained.

The survey of the Cupola Department's facilities indicated that the melting rate afforded by the three cupolas then in operation at the same time would not be sufficient to meet the required amount of 90 tons of iron per hour. It was decided, therefore, that four cupolas would have to be operated simultaneously and that the improved charging system would be based on serving the needs of four cupolas.

Existing Cupola Charging System

A detailed survey was made next of the existing cupola charging system to determine which methods and equipment could be retained. Particular emphasis was given to the methods and equipment used for handling and make-up of the metallic, coke, and limestone charge materials.

Metallic Charge Make-up

The 10-ton yard cranes transferred the metallic materials for the storage-yard

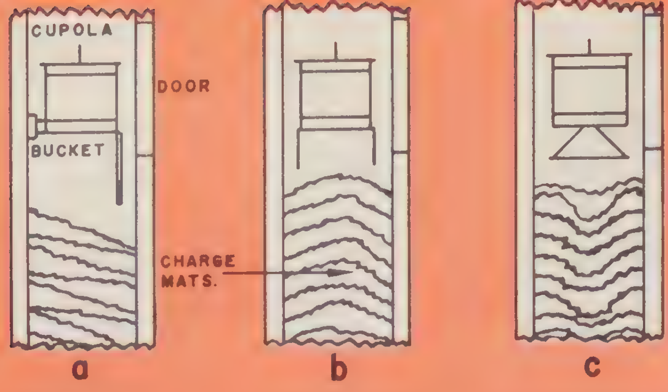


Fig. 3—Cupola charging buckets are important items of consideration in an overall charging system as they determine the manner in which the charges will be distributed inside the cupola. The theoretical material distribution of three types of charging buckets is shown: (*a*) single-bottom door bucket, (*b*) double-bottom door bucket, and (*c*) cone-bottom bucket.

bins to five charge make-up "docks" used to prepare hard- and soft-iron charges. The docks were located adjacent to the Cupola Department building. Fig. 1 shows an overall plan view of the docks, their relationship to the Cupola Department building, and an elevation view of a typical dock's construction. Only four docks were used actively. The remaining dock stored silicon, manganese, chromium, and phosphorous ferroalloy briquettes used for special metallic charges.

Each dock had eight inclined bins which aided the movement of material down each bin to the dock's flat work area. The bins contained metallic materials constituting a specific type of cupola charge. Two docks were used for hard-iron charges and the remaining docks for soft-iron charges.

The charge make-up operations were similar for the four active docks. The charge make-up for a hard-iron charge, for example, consisted of moving a rail-mounted scale car to the end of the dock until an empty cupola charging bucket, mounted on the end of the scale car, was in line with two bins containing steel bales and foundry and KCN pig iron. After the proper weight of each material had been loaded into the charging bucket, the scale car moved opposite two bins containing cast-iron scrap and the loading process was repeated. Because silvery pig iron is an important metallurgical controlling material, it was weighed accurately on a 500-lb platform scale before being loaded into the bucket. When all materials had been loaded, the scale car then moved into the cupola building where a transfer truck removed the loaded bucket and replaced it with an empty one. The scale car moved back to the dock and the cycle was repeated.

Metallic Material Charging

The metallic charge transfer truck then moved the fully loaded bucket to a charging crane pick-up point located on the first floor. The yoke of a 3-ton charging crane was lowered through a hatchway extending from the third floor to the first floor and was hooked to the bucket. The bucket was raised to the third floor and the materials charged into the cupola by the same crane. This charging sequence was performed for each individual cupola in operation.

Coke and Limestone Charge Make-up and Charging Operations

The cupola charging cycle at the Pontiac Motor foundry follows the standard practice of supplying alternate charges of coke and limestone and metallic materials, with the coke and limestone combined as a single charge.

The material handling operations for the coke and limestone differed appreciably from those employed for the metallic materials. The coke and limestone were unloaded separately from railroad cars into a pit-type hopper located within the storage-yard area. A single conveyor belt on which the coke and limestone were handled separately was positioned beneath the hopper and conveyed the two materials from the hopper to four coke storage hoppers and two limestone storage hoppers located above the third floor (the charging floor) of the Cupola Department building. (The coke, before reaching the storage hoppers, passed over a 1-in. wire mesh screen which removed fines and small coke particles, dust, and undesirable foreign material. A steel plate covered the screening section when limestone was conveyed.) Located at the end of the conveyor belt was a special unloading chute which directed the flow of coke or limestone into the storage hoppers. Fig. 2 shows schematic plan and elevation views of the coke and limestone storage hoppers and their relationship to the cupolas and charging crane.

Connected to the bottom of the storage hoppers were electrically vibrated chutes which moved the materials to four weigh hoppers. Each coke storage hopper supplied one weigh hopper and each limestone storage hopper supplied two weigh hoppers. These hoppers automatically weighed, by means of an internal scale, the quantity of coke and limestone required for each regular cupola charge.

Occasionally, the amount of coke and limestone required for a charge varied. To accommodate this variance, the weigh hoppers were capable of semiautomatic operation during the time any desired amount of coke and limestone was weighed separately.

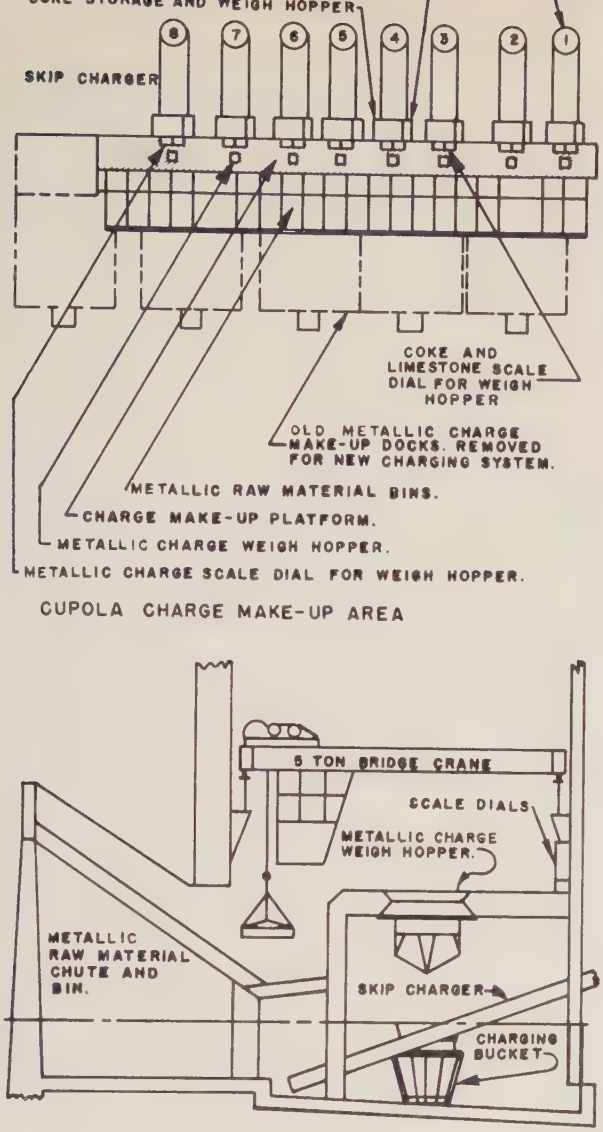
The coke and limestone charges then were loaded directly into charging buckets placed on the floor beneath the weigh hoppers. The transfer trucks moved the loaded buckets to a charging crane pick-up point where they were charged into the cupola.

Selection of Charging System Components

When the survey of the existing cupola charging system was completed, an analysis was made of its characteristics, along with an overall study of standard cupola charge make-up and charging operations and equipment used throughout the foundry industry.

The existing method for metallic charge make-up was essentially manual in nature. In order to decrease the time required for metallic charge make-up, the electromagnetic method of charge make-up was studied. This method uses an electromagnet to load metallic charge materials directly into scale-mounted charging buckets or the materials can be placed in a weigh hopper before being loaded into a charging bucket.

Electromagnetic charge make-up equipment is usually "tailor-made" to fit a particular cupola operation and, as a result, certain factors had to be considered when this method was contemplated. The major factors considered included the type and size of metallic materials to be handled, the number of



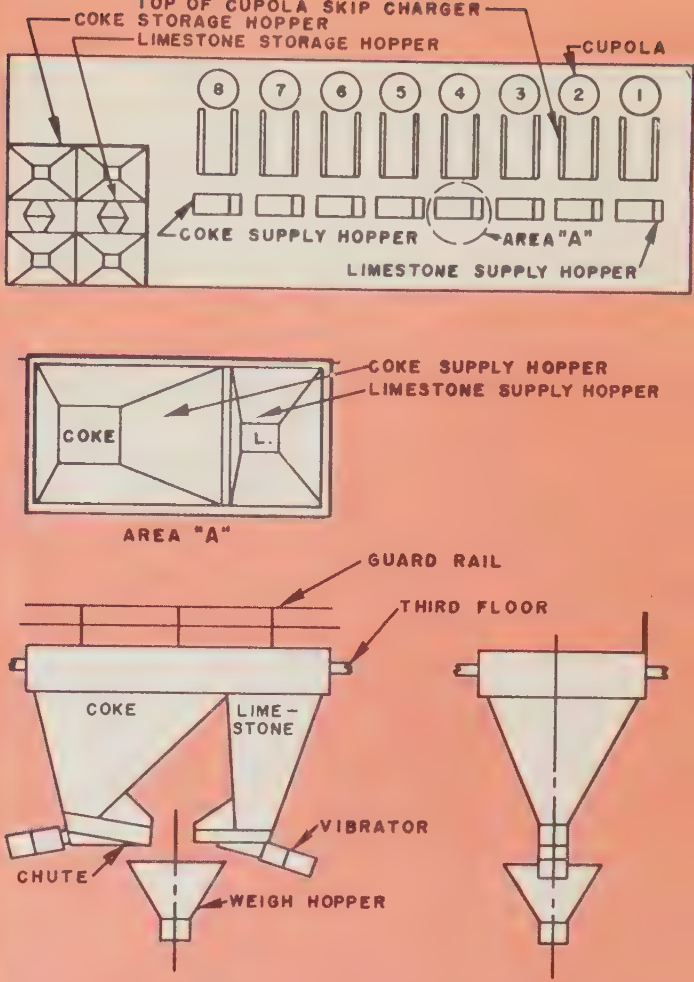


Fig. 5—The coke and limestone charge make-up area of the improved cupola charging system retains the previously used coke and limestone storage hoppers but, in addition, utilizes a gas-electric transfer truck to move the materials to supply hoppers. Each cupola has its own coke and limestone supply hopper which supplies these materials to a weigh hopper where they are semiautomatically weighed and dumped into a charging bucket (not shown) for subsequent introduction into the cupola.

Fig. 4—The metallic charge make-up area of the improved cupola charging system utilizes 20 bins to store all required materials. The bins are separated into two main groups and each group supplies two pair of cupolas. Two bins, which are centrally located and contain KCN (potassium cyanide) and silvery pig iron, supply all eight cupolas. Each cupola has its own individual metallic charge make-up weigh hopper which is supplied material from a 5-ton, electromagnetic lift crane. Four cupolas are operated simultaneously during one day's production—cupolas 1, 3, 5, and 7 one day and cupolas 2, 4, 6, and 8 the following day. Two cranes load the weigh hoppers of the operating cupolas.

different materials to be used in one charge, the weight tolerance for each material, the location of the charge make-up area, the type of charging equipment, and the time available for charge make-up. The overall analysis of the electromagnetic method was favorable, and it was decided that this method would be used for the new charging system.

Attention was directed next to the coke and limestone charge make-up operations. The existing method for conveying the coke and limestone from the pit-type hopper to the storage hoppers was deemed satisfactory and did not warrant change or modification. If any changes were necessary, they would have to be made either in the method used for measuring the coke and limestone or in the method used for transferring these materials from the weigh hoppers to the charging buckets.

The coke and limestone used in a cupola charge can be measured by two methods—weight or volume. The *weight method* measures the total mass of the coke and limestone, including moisture; the size and shape of the materials have no effect on the measurement. The *volume method* measures the total volume of the coke and limestone. The size and the shape of the materials, but not the moisture content, affect the amount measured. It was decided that the existing method of measuring the coke and limestone charges by weight was suitable for continued use.

Before the existing method used for transferring the coke and limestone from the weigh hoppers to the charging buckets was investigated as to its suitability, the various methods available for charging a cupola were first studied, with careful consideration being given to the time required for each method to deliver a charge.

In addition to the existing crane method for cupola charging, four other methods were studied for possible use. The first three methods studied—manual, charging trucks, and conveyor—were all considered undesirable. The amount of material required for charging into the four cupolas made the manual method impossible. The weight of the required metallic charges would be too heavy to

be handled effectively by either a crane-type charging truck equipped to handle any type of charging bucket, or a lift-type charging truck using a special dumping skiff for a charge container. The use of a conveyor for transferring materials directly from the charge make-up area to the cupola was not feasible because relocation of the metallic charge make-up area from the first floor to the third floor would be required. This, in turn, would necessitate elevating the 10-ton storage yard cranes in order to deliver the materials to the third floor. A conveyor system would be practical only for handling the coke and limestone.

The final method of cupola charging considered was *skip charging*. This method utilizes a trolley, mounted on fixed guide rails, to transport a charge container from the charge make-up area directly into the cupola. The charge containers used are sometimes detachable from the carrier which makes it possible for a charge to be made up ahead of time and stored until ready for use. The overall characteristics of the skip charging method, when compared to the existing method of charging by means of the 3-ton charging cranes, were very favorable for use with the proposed charging system—especially from the standpoint of time saved in delivering a charge directly from the make-up area to the cupola. Every aspect of skip charging was thoroughly studied from the construction and installation of required components to the overall control of the system. The method was considered economically feasible and was selected for use.

One of the most important items in the overall charging system still had to be considered—the type of charging buckets to be used. Charging buckets are important items as they determine the manner in which the materials are distributed inside the cupola.

There are many available types of cupola charging buckets but the three most widely used are single-bottom door buckets, double-bottom door buckets, and cone-bottom buckets (Fig. 3). The existing charging system used double-bottom buckets for coke and limestone charges and cone-bottom charging buckets for metallic charges. The proposed method of skip charging called for the metallic, coke, and limestone materials to be charged simultaneously. With this method, only one type of charging bucket could be used. Considerable study was given to selecting a charging bucket which not only would work well with skip charging but also effectively distribute the charge materials. The charging bucket selected was of the square top, side opening, cone-bottom type. It was selected because it compromised the advantages and disadvantages of the other types of buckets when only one type of bucket could be used. Each skip charger (every cupola would have its individual charger) would be equipped with an individual bucket and each bucket would be large enough to handle one regular charge of metallic materials, two regular charges of coke, and two regular charges of limestone at the same time.

When the basic components of the proposed cupola charging system had been established, work was directed toward finalizing the operational details of the overall system.

Improved Cupola Charging System

Every operation connected with the overall cupola charging system was designed on the basis of supplying the charges at the required rate to provide the melting demand of 90 tons of molten iron per hour. It became necessary to change completely or to modify some of the existing equipment and facilities in order to provide complete compatibility with the new methods to be used for charge make-up and charging.

Metallic Material Handling

Fig. 4 shows a plan and elevation view of the new metallic charge make-up area. A major change was made in the handling procedure for metallic materials. The five charge make-up docks were removed and replaced by 20 inclined chutes which guide materials into 20 storage bins located in the charge make-up area. The bins are separated into two main groups and each group contains necessary materials to supply two pairs of cupolas. Two separate bins, containing KCN pig iron and silvery pig iron, are centrally located to supply all eight cupolas. The metallic materials are transferred from the storage yard by the 10-ton yard cranes. The materials are moved from the bins to eight metallic charge weigh hoppers—one for each cupola—by two, 5-ton bridge-type cranes, each equipped with a 45-in. diameter, rheostat controlled, electromagnetic lift. One 5-ton crane supplies the weigh hoppers for cupolas 1 through 4 and the other crane supplies cupolas 5 through 8. A third crane is available for emergency use and for lifting nonmetallic materials through the hatchway from the ground floor to the charging dock.

Coke and Limestone Handling

The four coke and two limestone storage hoppers and the conveyor used for transferring these materials to the storage hoppers were retained for continued use. A change, however, was made in the manner in which the coke and limestone are handled from the time these materials leave the storage hoppers until they are charged.

Fig. 5 shows plan and elevation views of the coke and limestone charge make-up area. The coke and limestone handling method centers about transferring the materials from the storage hoppers to the supply hoppers and finally to the weigh hoppers. Each cupola has its own coke and limestone supply hopper and weigh hopper. A transfer truck which has a hopper mounted on its frame, transfers either coke or limestone from the storage hoppers to the supply hoppers. This truck was converted from one of the former cupola charge transfer trucks. The scales and vibrating chutes on each existing coke storage hopper were removed and the pneumatically operated, clam-shell-type bottom doors were lowered. The limestone storage hoppers were handled in the same manner, and one of the two gate hoppers at the bottom of each storage hopper was closed off and removed so that each hopper feeds into one set of unloading gates. One truck driver manually operates the unloading gates to load the transfer truck and delivers the materials to the proper supply hopper.

Charge Make-up and Charging Procedure

The charge make-up and charging procedure is similar for each cupola. The overall charging system is based on supplying charges for cupolas 1, 3, 5, and 7 one day and cupolas 2, 4, 6, and 8 the following day, although any arrangement can be used. Fig. 6 shows a schematic elevation view of the charging system arrangement for one cupola. Each cupola is charged with materials from an individual charging bucket transported by a rail-mounted trolley on a skip charger.

The metallic charge make-up procedure relating to cupola 1 is typical of the procedure employed for all eight cupolas and is outlined here for purposes of illustration. The metallic materials stored in the group of bins supplying cupola 1, as well as cupola 2, are loaded separately into the weigh hopper by the 5-ton, electromagnetic lift crane. The crane operator determines the weight of each material loaded into the hopper by observing a wall-mounted, dial-face scale strategically located near the weigh hopper. The dial is marked in such a manner as to inform the operator of the order and required weight of each metallic material to be loaded. The KCN and silvery pig irons required for a charge are stored in piles on the charge make-up platform near the weigh hopper. Because these materials are important for metallurgical control, they are manually loaded into the weigh hopper. The KCN pigs have the same weight and are added separately, by number, to the weigh hopper. The silvery pig iron required for a charge is first accurately weighed on a platform scale, located near the silvery pig iron bin, before being added to the weigh hopper. After all metallic materials have been loaded into the weigh hopper, the bottom doors of the hopper are opened pneumatically and the materials emptied directly into a cone-bottom charging bucket positioned beneath the hopper. An operator then sets the skip charger into operation moving the charging bucket upward until it automatically stops directly beneath the coke and limestone weigh hopper.

The skip charger utilizes a trolley to transport the charging bucket. Two steel cables, wound around a steel drum which is powered by an electric motor and gear reducer arrangement, raise and lower the trolley along fixed guide rails.

Each coke and limestone weigh hopper receives material from one coke supply hopper and one limestone supply hopper. The supply hoppers, in turn, receive material directly from the transfer truck. The coke and limestone are semi-automatically loaded, separately, into the weigh hopper. When a coke and limestone charge is to be made up, an operator first sets into operation an electrically vibrated chute, located underneath the coke supply hopper, which transfers the coke from the supply to the weigh hopper. When the desired amount of coke has been loaded into the weigh

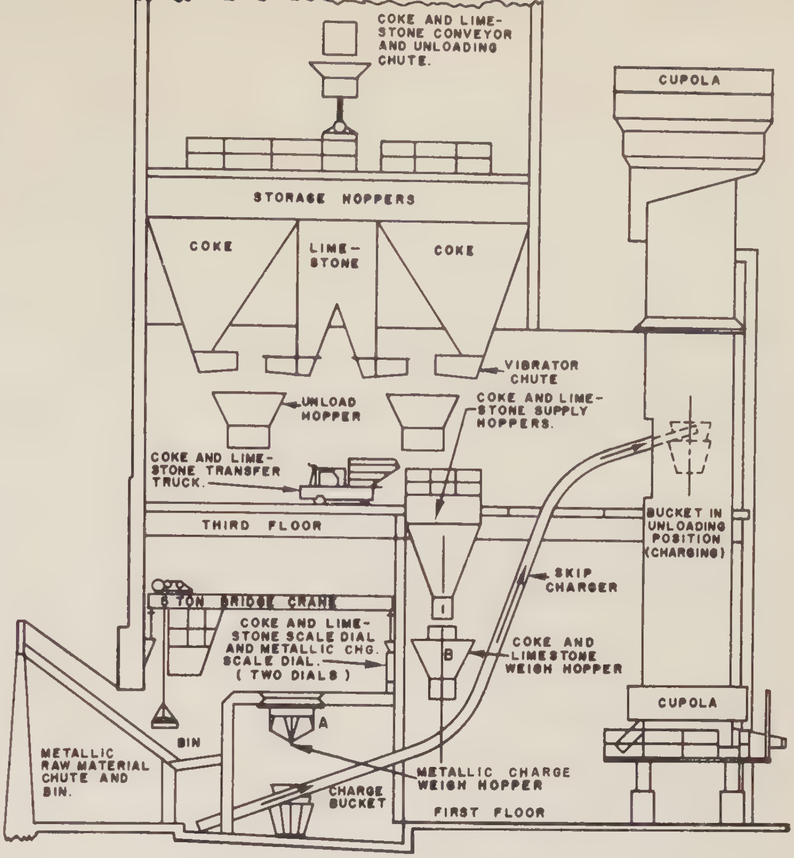


Fig. 6—The improved cupola charging system utilizes a rail-mounted trolley on a skip charger to transport a charging bucket directly into the cupola. The bucket is positioned under the metallic charge make-up weigh hopper (*A*). After the metallic charge is made up, it is dumped directly into the bucket which then moves upward, and automatically stops under the coke and limestone charge weigh hopper (*B*). The coke and limestone are dumped directly over the metallic materials. The bucket then is put into operation and moves into the cupola, deposits the charge, and returns automatically to the metallic charge weigh hopper. Each cupola has its own charging bucket, metallic charge weigh hopper and scale, coke and limestone charge weigh hopper and scale, and skip charger.

hopper, an automatic scale mechanism operates an electrical control which shuts off the coke-chute vibrator and sets a similar vibrator, connected between the limestone supply hopper and the weigh hopper, into operation. When the desired weight of limestone has been loaded into the weigh hopper, the scale mechanism operates an electrical control which automatically stops the flow of limestone. The limestone can be loaded before the coke if so desired. The charge of coke and limestone then is emptied directly on top of the metallic materials in the waiting charging bucket. The skip charger is set into operation and the charging bucket moves into the cupola and deposits the charge. The skip charger returns the bucket to the metallic material weigh hopper immediately after the charging operation has been completed.

The charge make-up operations for the metallic materials and the coke and limestone are continuous. When the skip charger transports the charging bucket from the metallic charge weigh hopper to the coke and limestone weigh hopper, the charge of coke and limestone is emptied immediately into the charging bucket.

Summary

The improved cupola charging system has provided the solution to the problem of providing more molten metal to meet increased iron casting production. Utilization of delayed action electromagnetic metallic charge make-up equipment and the skip charger method of cupola charging has made it possible to provide each operating cupola with a charge in the required time necessary to maintain the desired melting rate. Also, much of the human effort previously connected with charge make-up operations has been eliminated.

The development of the improved cupola charging system is a typical example of engineering improvements which become necessary from time to time in a manufacturing organization. Original equipment and methods of operation frequently must be improved to keep pace with present day requirements.

Some Principles of Methods and Motion Study as Used in Development Work

By RICHARD R. FARLEY
Process
Development
Section

In today's manufacturing plant, the machine, the assembly operation, or the process all have been designed, obviously, for the best possible performance and efficiency. But all machines and processes—even the so-called completely automatic—are controlled by human operators. Thus, it is the man-machine combination which results in the product and the overall output is evaluated as man-machine performance. Designers of machines and industrial operations, therefore, must give attention to principles applying to the human element in the man-machine relationship for the proper functioning and ease of operation of the machine. In General Motors equipment is designed on the basis of the man-machine system. Such designs require the application of a number of principles of methods and motion study affecting, for example, work-space limits for the female or male operator, manual activity of the operator, the force and the motions which the operator can best use, and the proper arrangement of information for visual response.

When the human operator can reach, lift, and see easily, the machine has been well designed

FROM the beginning of time, man has striven to improve the effectiveness of his individual effort. The cave man found that simply by fastening a stick to his axhead he could get more striking force from the same amount of effort. Primitive man found that by using a section of a log as a roller he could move heavy objects from place to place more easily. The wheel developed from this simple discovery.

The combination of these and other principles has resulted in today's modern machines. For centuries now it has been man and machinery combined that do the work. Because this relationship of man and machines has, from the beginning, always been so very close, it is only natural that today's methods engineers accept this relationship as a common element in any development area—even in the so-called completely automatic machines.

Development projects in the man-machinery field are defined as *man-machine systems* wherein the human element inter-reacts with the mechanism and the overall output of the system is evaluated as man-machine performance.

In adopting a position that accentuates the importance of the operator, methods engineers have taken into consideration the physical capabilities and limitations of the human element, as well as the psychological and physiological mechanisms of the operator as component elements in the design of man-machine systems. These elements first are established, then evaluated, and finally designed into the man-machine system concurrently with the electrical, electronic, and mechanical elements.

As an aid to the understanding of the use of methods and motion study in machine development work, it is helpful to discuss the elements of operator evaluation as they are considered and applied in General Motors by the various Divisions working closely with the Process Development Section of the General Motors Manufacturing Staff.

Work Space

The first consideration is *work space* which may be defined as the space allotted to an operator assigned to a fixed position or to an entire plant as would be the case for intra-plant material handling personnel.

Operator work space is normally defined as the total space in which an operator performs his duties.

Normal man-machine systems limit the spatial evaluation of operative personnel to a fixed operator position in which the available work space is subdivided into segments of spatial volume as follows:

(a) *Maximum available work space* is equal to the volume circumscribed from the minimum limb flexion to maximum limb extension of an operator.

(b) *Maximum normal work space* is equal to the volume circumscribed by the movement of the fully extended arm pivoting about the shoulder pivot point.

(c) *Normal work space* is equal to the volume circumscribed by the horizontal forearm pivoting about a relaxed vertical upper arm.

The most desirable work space is the normal work space segment (c). The allocation of operator space generally is established on the basis of the physical dimensions of an average sized male or female operator (Fig. 1).

It is usually considered that normal work space desirability is a function of minimum movement, which simply means that the shorter the distance of a movement the less will be the operator fatigue and time requirement.

Design application of the work space concept is promoted and maintained through the use of operator work space data sheets (Fig. 2) and draftsman templates (Fig. 3), which reduce the total spatial concept to planes of working areas at various elevations.

Manual Activity

With the dimensional boundaries of the operator's work space having been defined and established by the physical dimensions of the average operator, it is possible then to establish the manual operation to be performed within the work spaces.

In order to establish systematically and logically or to study manual activity, it is necessary that a method of recording be established. The study of an existing operation may be recorded by motion pictures. Although the motion picture study produces good results, the expense

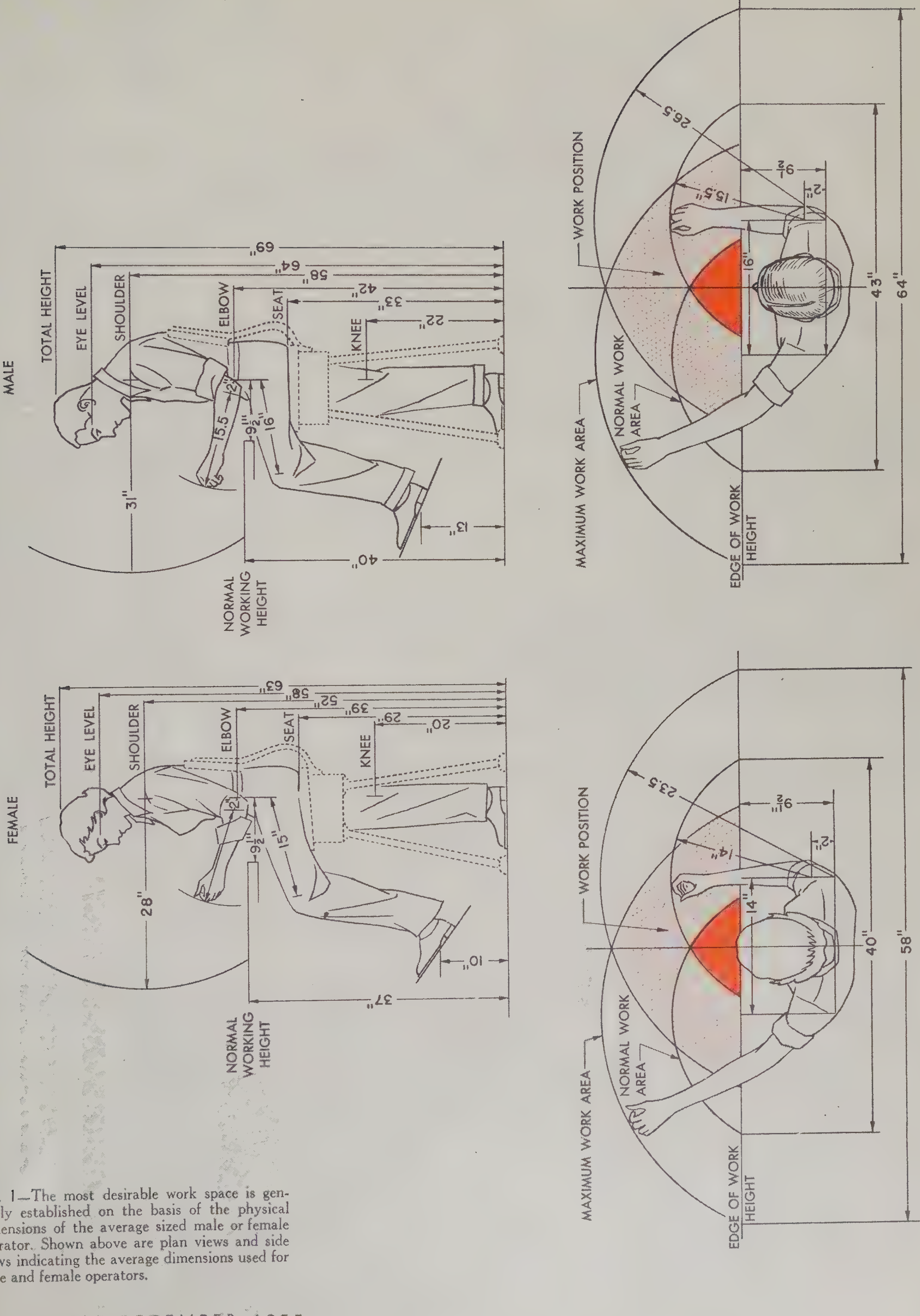


Fig. 1—The most desirable work space is generally established on the basis of the physical dimensions of the average sized male or female operator. Shown above are plan views and side views indicating the average dimensions used for male and female operators.

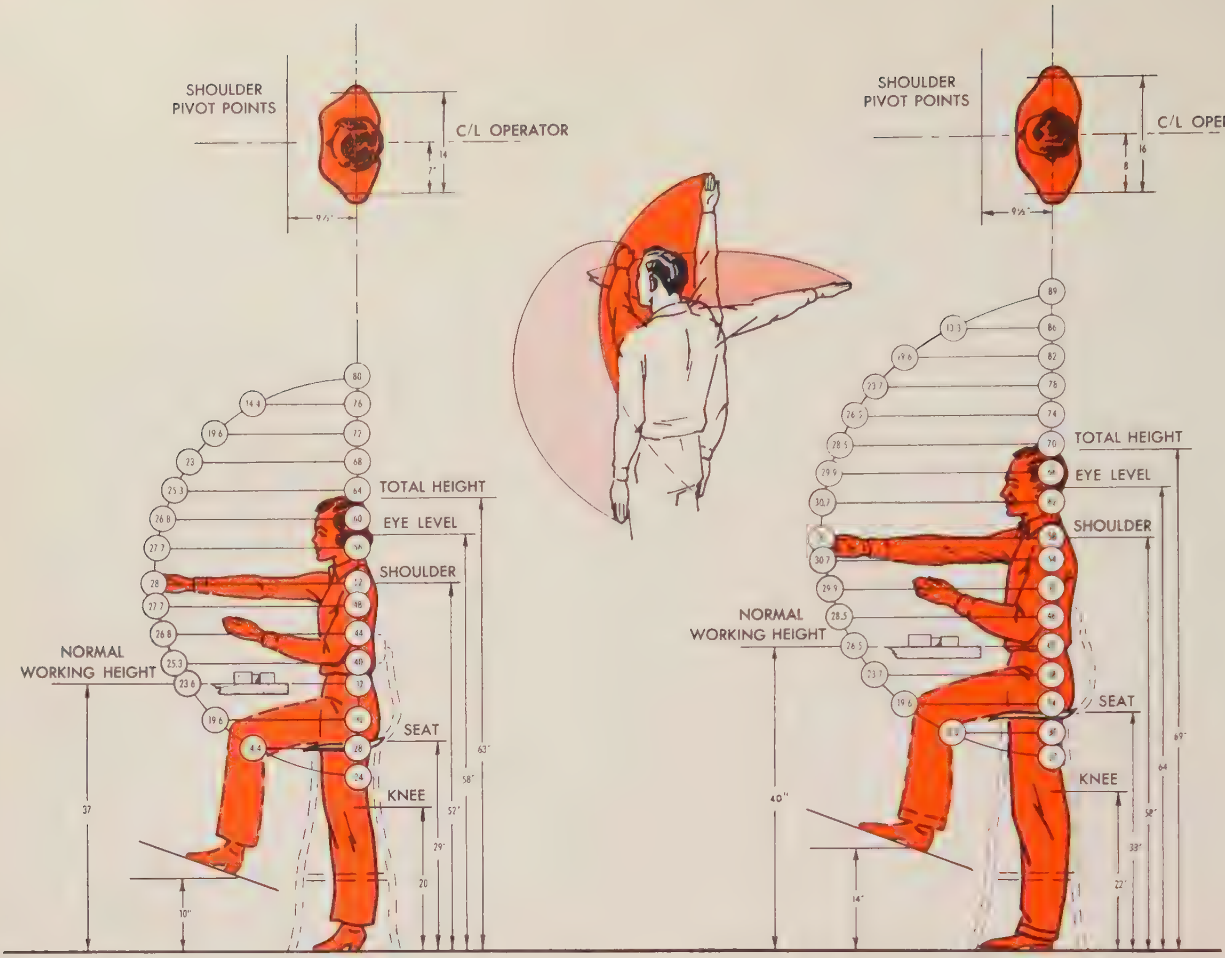


Fig. 2—A work space data sheet provides dimensions for establishing operator-job relationships. This data sheet, developed by the General Motors Methods Engineering Committee and the Work Standards and Methods Engineering Section of the General Motors Manufacturing Staff, gives views of average operators demonstrating the sitting-standing principle and maximum horizontal reach at various elevations. This data sheet can be used to determine work space relationship by establishing shoulder pivot points on a plan view of the designer's drawing. A compass is set to the horizontal displacement corresponding to the elevation being evaluated. The compass is then pivoted from the shoulder pivot points previously established on the plan view of the drawing. The area enclosed within the radius is equal to the maximum operator work area at the elevation previously considered.

of the necessary equipment and photographic personnel is not always justified.

An alternate recording procedure to the motion picture film is a written word description. Written word descriptions must be developed in such a way as to allow for communication, detailed study of both of the operator's hands, and sequence of operations performed.

To satisfy the need for a common pattern for a written description that would meet the prerequisites of such a system, a technique termed act breakdown has been established.

Act breakdown is a technique for recording and analyzing an operation by relating the left- and right-hand activity of an operator through the use of acts. An *act*, in turn, is defined as the term applied to a grouping of operator movements which can be used to describe manual activity for man-machine system studies.

To provide a uniform means of recording, standard terms have been adopted and defined for use within an act breakdown (Table I).

The application of the terms to establish an act breakdown record can be demonstrated easily in a written act breakdown recording of the common manual operation of dialing a telephone number. The act breakdown is recorded in a specific pattern which now establishes uniformity of terms as well as method of recording (Table II).

In this example, *get* acts were used to describe the manual movements required to gain control of an element so that it could be moved to its next destination. Example:

- Get dial
- Get receiver from cradle.

The *place* acts were used to describe the manual movements required to move an element to a specific location. Example:

- Place dial to end stop
- Place receiver to ear.

The *dispose* acts were used to describe the manual movement required to release an element without regard to its final position. Example:

- Dispose dial.

Process was used to define the change in condition of telephone receiver.

Wait was used to describe the suspension of direct activity.

Hold was used to describe the keeping of the telephone receiver to the ear or maintaining a relative position.

From this example of act breakdown,

it is evident that there has been established a technique for recording manual operator activity which can be applied readily to existing job study as well as planning new operations.

Although this technique can be used to study manual operation to detect potential improvements, it is limited in its ability to supply all the information required because of the absence of any time values. Time values must be devised in the planning of an operation whether it be purely manual or a balance in a man-machine system. The predetermination of the amount of time required to perform a particular operation requires individuals who are trained and skilled in this operation.

A fundamental principle in planning a manual activity is that the operation be designed to result in minimum operator movement as contained within acts and a minimum number of acts as contained within the act breakdown.

Sensitory Response

Thus far this discussion has been limited to the physiological mechanisms

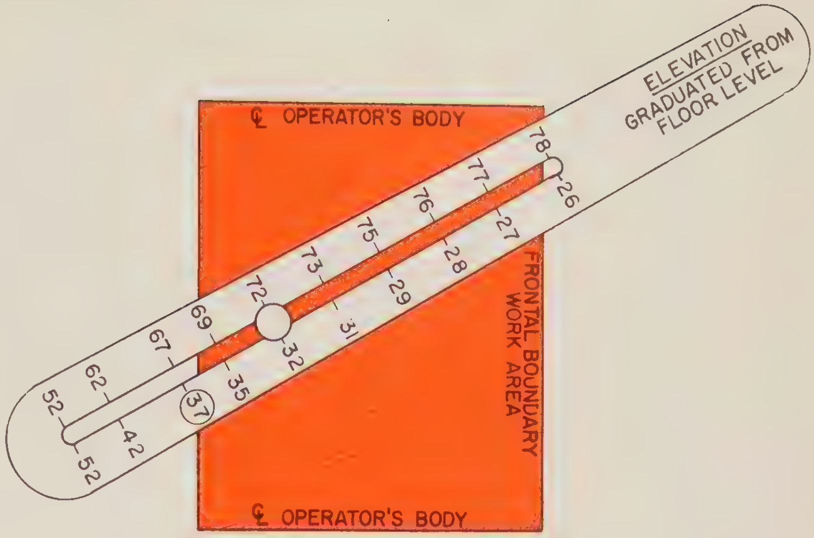


Fig. 3—This template aids the draftsman in laying out work space dimensions. The template is used in the following manner: (a) the template is placed on the plan view with the edge labeled "frontal boundary work area" coinciding with work area edge on drawing, (b) either the left or right side of the template base is placed in a position representing the centerline of the operator's body, (c) the maximum work area at any elevation is determined by adjusting the swing arm to a specific elevation (graduated on the swing arm—calibrated to button pivot point). The area circumscribed by the end of the pivoted swing arm is equal to the maximum work area at the established elevation.

COMPONENT TERMS OF THE ACT BREAKDOWN TECHNIQUE

An **act** is the term given to a grouping of movements which can be used to describe manual activity for method study.

The **get act** consists of the muscular movements required to move to an object and to gain full control of that object so that it can be moved in a straight motion path to its next destination.

The **place act** consists of the muscular movements required to move an object into a definite position and release or hold it there.

The **dispose act** consists of the muscular movements required to move an object in a given direction and release it without reference to its final position.

Process is the application of a mechanical, chemical, or other means which changes the size, shape, or condition of the object.

Wait is a suspension of directed activity on the part of the operator for justified or unjustified reasons.

Hold is keeping an object in a definite position relative to another object so that the holding member does not perform any movements.

Table I—The *act breakdown* is a technique for recording and analyzing an operation by describing and relating the left- and right-hand activity of the operator through the use of the acts—get, place, dispose—and the terms—hold, wait, and process. To provide a uniform means of recording the description of an operation being studied, standard terms have been adopted and defined for use in the act breakdown as shown in this table.

EXAMPLE OF ACT BREAKDOWN

Left Hand	Right Hand
Get telephone receiver from cradle	**Wait**
Place telephone receiver to ear	**Wait**
Hold receiver to detect dial tone	**Get** correct position of dial for first element to be dialed by inserting finger
Wait	**Place**—dial clockwise to stop position; leave finger in dial position
Wait	**Dispose**—dial by removing finger Repeat above three acts for each number or letter to be dialed
Place receiver to ear	**Wait**
Hold receiver to ear to detect signal	**Wait**
Assuming No Answer	
Place receiver in cradle	**Wait**

Table II—The uniformity of terms and the method of recording information in the act breakdown are illustrated in the simple operation of dialing a telephone.

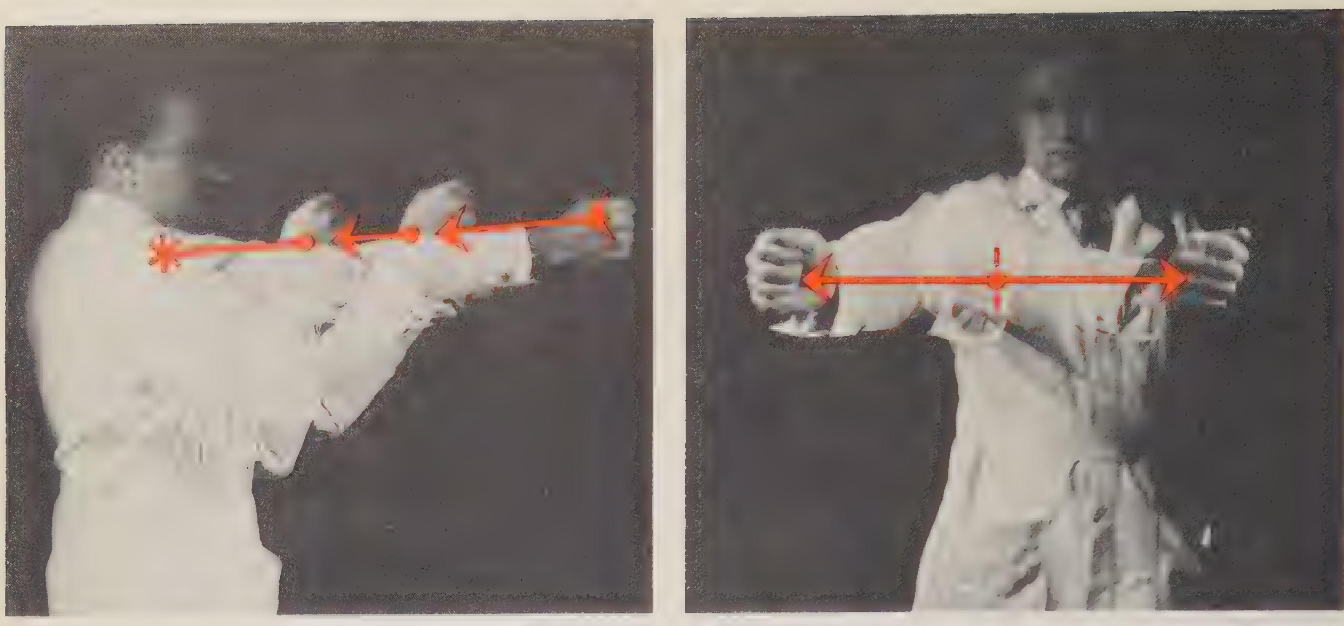


Fig. 4—Illustrated here are the proper and improper methods of utilizing the operator's muscular reaction forces. For best performance the forces should have their line of travel intersect the shoulder pivot point as shown on the left. Improper motion, where the path of travel does not intersect the shoulder pivot point, is shown on the right.

of man. It has not considered the operator's sensitory response which directs the motion described, but has established the importance of physically planning a work space to complement the physical limitation of an operator.

It is equally important, however, to complement the operator's muscular limitations, responses, mechanisms, and sensitory elements. Therefore, *force* should be considered in this discussion. An operator's *muscular reaction force* is defined as the force required to be exerted by an operator to produce a motion.

Although clearly defined in dictionary terms, force is very difficult to evaluate as a quantitative value. Magnitude of force, frequency of application, and direction of application each form a portion of a total reactant force evaluation. Thus far, no values have been obtained for directed force or factors for sub-evaluation of frequency and direction. Important concepts for design relative to the operator's muscular reaction force are as follows:

- For optimum utilization of an operator's muscular reaction forces, motions requiring exertion of muscular reaction forces should have their line-of-travel path intersect the shoulder pivot point (Fig. 4).
- Rotary motions should have their rotational axis perpendicular to a line drawn from the center of the

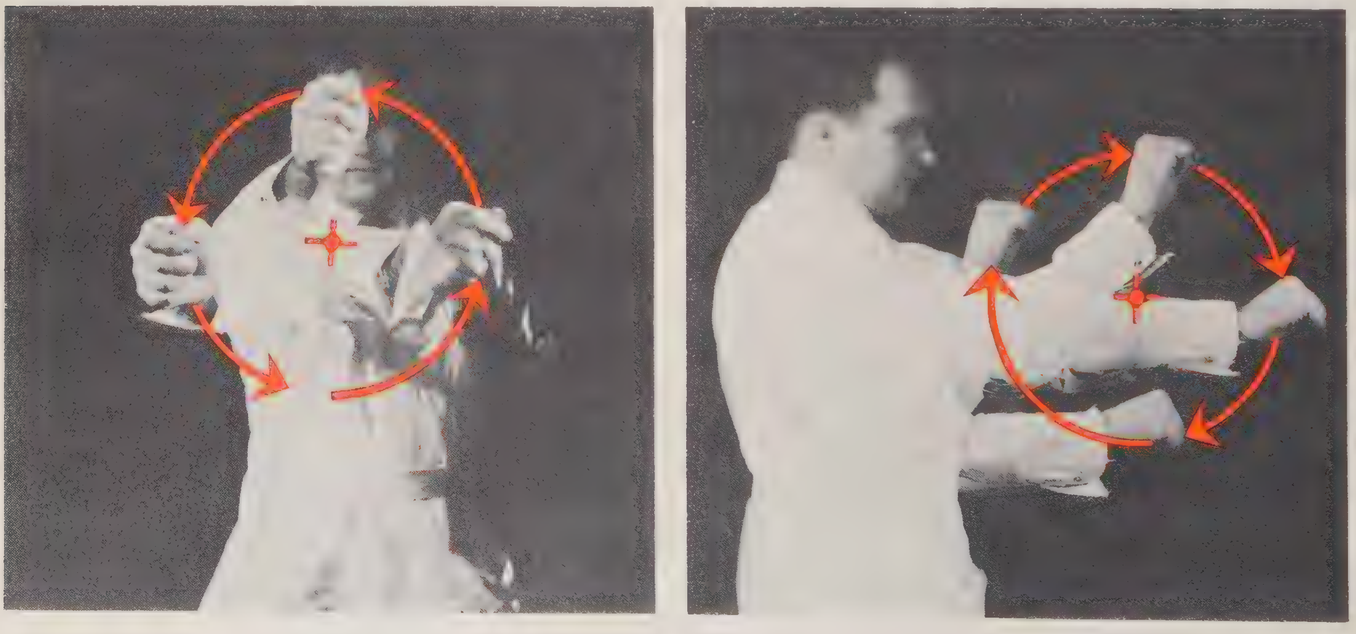


Fig. 5—For the optimum condition of rotary motion, the rotational axis of the motion should be perpendicular to a line drawn from the center of the rotary motion to the shoulder pivot point, as shown on the left. Incorrect rotary motion is shown on the right.

Fig. 6—The familiar automobile instrument cluster serves as an example of the principles of visual information displays. A check or on-off display indicates absence or presence, good or bad. Examples are the indicators for the headlight high beam and the battery charge or discharge condition. A qualitative or directional display indicates function or malfunction and direction. Examples are the gasoline and temperature gages. A quantitative display indicates precise numerical information exemplified by the speedometer.

rotary motion to the shoulder pivot point (Fig. 5).

- All muscular reaction forces that are not directed through the shoulder pivot point are vector components of the force that could be applied if the force were directed through the shoulder pivot point.

Methods engineers have not as yet mastered the fundamentals of operative manpower nor do the concepts outlined above have quantitative values.

The determination of quantitative values is but one of many elements that must be established in order to plan future man-machine systems to approach a state of perfection.

Visual Information Displays

Visual displays are used extensively in man-machine systems involving applications for quality control and require the engineer to evaluate carefully the human element. For example, the intensity of a signal light must not be objectionable to the human element but must be of sufficient strength to afford a decided contrast. Generally, these systems contain a series of information displays such as gages, dials, and lights which may be categorized as (a) check or on-off, (b) qualitative or directional, and (c) quantitative. A familiar example of this type system is the automobile instrument panel (Fig. 6).

The placement, grouping, and design of visual displays are as important as the actual choice of the display itself. Displays that are neither accessible nor readable are of no value. Multiple quantities of a similar display dial should be grouped to produce a symmetrical pattern so that any deviation from the mean value will impart a lack of symmetry which is easily detected (Fig. 7). Display placement should be arranged in a pattern depending on frequency and sequence of use. This very often may result in a compromise.

The displays so far mentioned apply to the visual sense of the human element only. The auditory sense of the human element is also a component. It is sometimes neglected, however, for industrial applications. This may be due to the fact that the reaction time for an auditory signal is approximately one and one-half times as long as for that of a visual response, and that the overall summation of repetitive auditory signals is an objectionable feature. Auditory signals normally are applied as non-frequent signals, such as for emergency purposes.

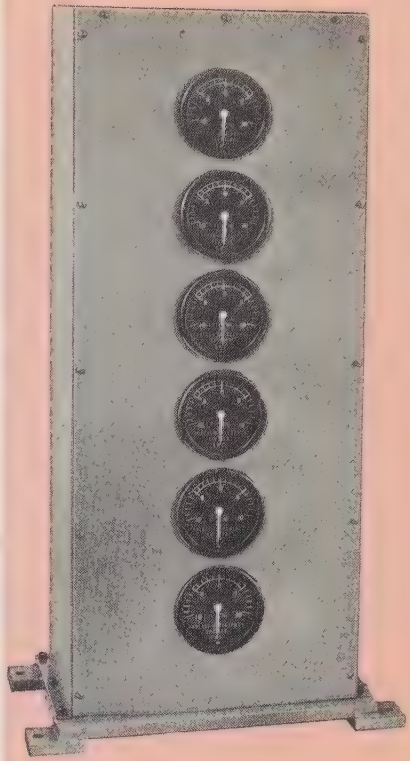


Fig. 7—A symmetrical pattern should result from proper grouping of multiple quantities of similar dials. With the information displayed in this manner, any deviation from the mean value will impart a lack of symmetry which is easily detected.

Conclusion

In development work for machines and industrial operations, the engineer needs to apply the principles of methods and motion study to achieve the best results from the man-machine system. Knowing the dimensional boundaries of the average operator's work space, the manual operation can be designed properly for that work space. A technique known as act breakdown aids in recording data on the operator's manual activity; these data then are used in the design of new systems or in the improvement of existing ones by eliminating certain motions or steps. Information on human muscular movements also can be studied so that the design will result in the least operator fatigue. The visual and auditory responses of the operator also receive the attention of the designer in development work.

The methods engineer has come a long way in the study of man-machine systems; he has a long way to go to obtain perfection. He is constantly studying, improving his knowledge, and passing the benefits on to his fellow workers so that all mankind will benefit.

Applying the Principle of the Unit-Load to the Packaging of Automotive Hardware

By JOHN F. CURTIN
Ternstedt
Division

The handling and packaging of millions of automotive hardware parts present many challenging problems to the packaging engineers at Ternstedt's plant in Trenton, New Jersey. A system of palletized unit-loads has reduced both labor and material costs while at the same time increasing the efficiency of materials handling operations in the shipping, receiving, and warehousing of parts.

Palletized unit-load cuts packaging costs, simplifies material handling operations

The Trenton, New Jersey, plant of Ternstedt Division produces about a million pieces of automotive hardware daily. More than eight hundred and fifty different parts are manufactured for domestic use and some two hundred and fifty additional ones for General Motors Canadian operations. These parts must arrive at the right place, at the right time, in the right quantity, and—most important—must reach their destination undamaged. The continuous search for more economical methods of packaging a changing variety of hardware parts presents a constant challenge to the packaging engineer.

To give some idea of the scope of the Ternstedt-Trenton plant's packaging operation, over one and one-half million dollars have been spent during the 1955 model year for such packaging materials as corrugated cartons, wood pallets, paper bags, chipboard, and sundry other packaging aids. It is no wonder, then, that much attention is being given to the potential savings in this area of manufacturing through the development of better packaging techniques.

RECEIVING PURCHASED PARTS

In 1948, a system of palletized unit-loading was instituted at the Trenton plant as a means of improving the packaging and handling of the millions of parts which the plant manufactures for the various GM car Divisions. In 1953 the system was broadened to include materials received from vendors. Specifically, the objectives of the latter program were as follows:

- Eliminate inconsistencies in vendor packaging
- Place all vendors on an equal packaging cost basis
- Allow faster unloading of trucks at receiving docks
- Specify packaging to provide maximum convenience at the point of use
- Promote more efficient storage, improved inventory control, and better housekeeping
- Make maximum use of mechanical handling equipment
- Eliminate repacking outbound parts
- Make more efficient use of carrier's facilities.

With these objectives as working goals, packaging engineers proceeded to design a palletized unit-load for purchased materials which would integrate vendor packaging into the plant's material handling system as much as possible without undue cost. This part of the planned materials flow throughout the entire plant was developed in close cooperation with material suppliers. At the same time attention was directed to application of the same principles of

Fig. 1—The disadvantages of uncontrolled vendor packaging are shown in this view of Ternstedt's parts warehouse (Trenton, New Jersey) two years ago. It is not difficult to visualize the receiving, storage, and inventory problems caused by this varied packaging.

Fig. 2—The warehouse as it appears today shows the results achieved through a cooperative program with vendors for the "unit packaging" of purchased parts.

Fig. 3—Purchased parts are moved directly from trailers onto roller type conveyors, there being no intermediate drop. A production line system has been set up to receive, count, and inspect for quality all materials brought into the plant.

Fig. 4—As specified, unit-loaded glass channels are received from the vendor in the unit pack, stacked and glued on a standard pallet. In instituting a program of specifying vendor packaging, much thought was given to the reuse of the vendor's packaging materials. Hence, incoming containers are specified to fit outbound container requirements. All unit-load material is packed in slotted, double-wall corrugated cartons of 275-lb test. Each carton is one-half the size of a standard 41 in. by 35 in. pallet so that two cartons may be placed side by side on the pallet and capped with a common cover. Each layer of cartons is glued to the under layer with the bottom layer being glued to the wooden pallet. The glue prevents shifting of the load on the pallet, either when in transit or when stacked in tiers in the warehouse. For those parts not subject to unit-loading, two basic carton sizes are specified, 12 in. by 11 in. by 12 in. and 12 in. by 11 in. by 6 in. Both of these sizes are easily loaded on a standard pallet.

unit-load packaging developed for vendor materials to outbound shipments of automobile body hardware and trim parts manufactured in the plant. Thus, specifications were established for corrugated containers, wood pallets, and a variety of packaging aids—all of which were aimed at improving the packaging for both incoming materials from vendors and manufactured parts being shipped to GM plants in 32 cities located in 16 states and Canada.

Conclusions

In the constant effort to improve materials handling, the packaging engineers of the Ternstedt-Trenton plant have developed unit-load packaging techniques designed for a variety of applications. To promote smooth flow of parts, both purchased from vendors and manufactured in the plant, emphasis was placed on standardization of packaging materials and techniques.

The unit-load concept clearly proved the best solution to numerous packaging problems. Unit-loads were specified to fit one standard pallet affording a maximum of strength and occupying a minimum of space. Adapted to standard cartons, interior packaging aids were devised for the large variety of parts, providing increased compressive strength to allow further stacking of the palletized unit-loads in the warehouse.

Improved packaging techniques have resulted in an overall savings in material costs, warehouse space, and handling time. Other advantages of the palletized unit-load are: less accident potential because of reduced traffic, better employe morale through the elimination of heavy manual effort, more efficient transfer of materials from production areas to warehouse or freight cars, more efficient use of shipping and receiving docks due to decreased time for loading and unloading, and the maximum utilization of mechanical handling equipment.

SALVAGE OPERATIONS

Fig. 5—The materials in which incoming parts are received are processed through a salvage operation in which a beveled pry bar is used to separate the glued sections, staples are removed, and the flap sections of the covers are cut off. The two cartons originally glued to the pallet remain intact, as shown, ready for reuse. Previous carton markings are obliterated. Working closely with the Engineering and Plant Layout Departments, space is provided in designated areas in the various manufacturing departments for the accumulation of these salvaged packaging materials. Savings resulting from the salvage program are calculated on the value of the new materials which the reused cartons replace. The salvage program is only supplemental to new carton purchases and during 1955 will reduce these purchases by approximately three and one-half per cent.

NEW MATERIALS

Fig. 6—New packaging materials for outbound shipments were formerly received in bundles as illustrated by these corrugated cartons and pads. Six man-hours were required to unload from a trailer and place on pallets 800 bundles of these cartons.

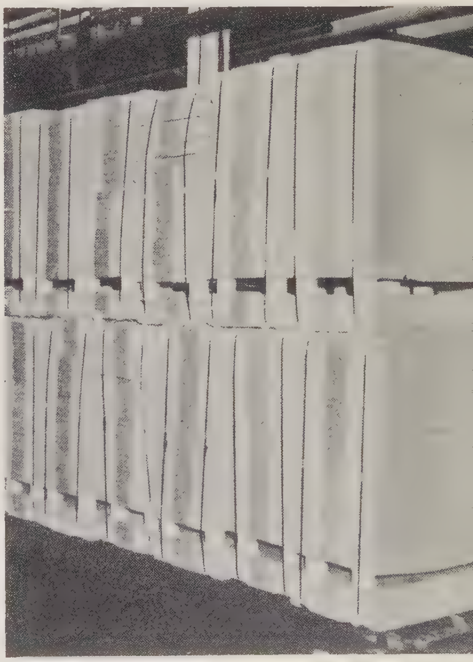


Fig. 7—In the revised system, 20 unit-loads are equivalent to 800 bundles. These 20 units are unloaded and stored in 30 minutes by one man operating a fork truck—one-twelfth the time required with the bundle method. Approximately eighty-five per cent of all packing materials now received at the Ternstedt-Trenton plant arrive in unit-loads. This method is neater, safer, allows easier counting, and reduces damage.

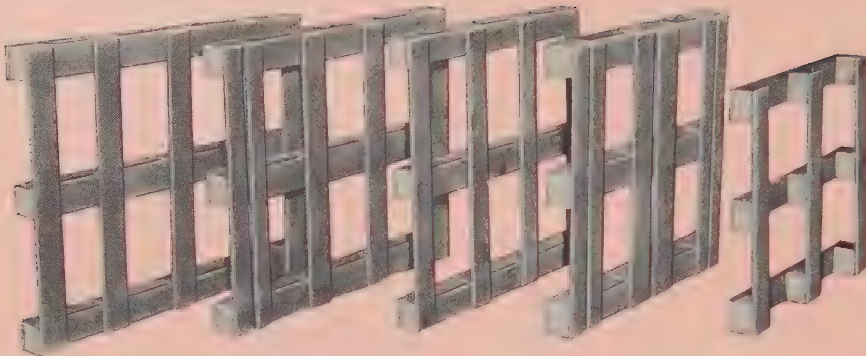


Fig. 8—The pallet has long been recognized as an efficient tool for the handling of packaged goods, but standardization of sizes has been relatively slow. At the Ternstedt-Trenton plant five different pallet sizes were used to handle 16 different types of corrugated assemblies.

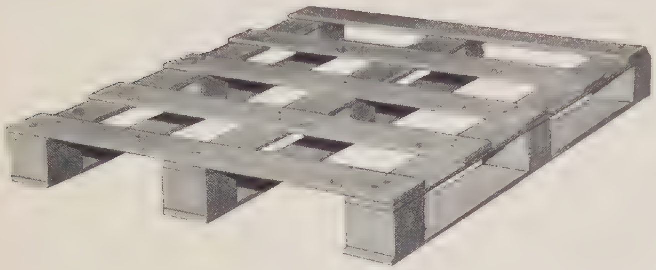


Fig. 9—The new unit-load system reduced the number of pallet sizes from five to one, the standard 41 in. by 35 in. pallet shown here. The number of corrugated assemblies required was reduced from 16 to 5. This multi-purpose pallet is sufficiently adaptable to ship a wide range of parts totaling some 8,000 unit-loads each month.

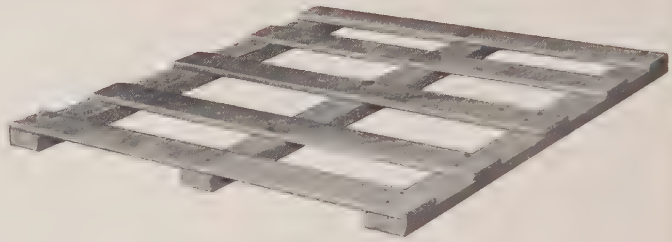


Fig. 10—In order to decrease further the overall size of the palletized unit-load, considerable attention was directed to pallet design. This work resulted in the no-block pallet constructed of rough, re-sawed hardwood in simple lattice design. The stringers are full dimension 1 in. by 3 in. boards and the deck consists of five, full dimension, ½ in. by 4 in. boards. With this design, the nine 3 in. by 4 in. by 4 in. blocks used on conventional pallets are no longer needed, yet the pallet is stronger and less vulnerable to damage.

Fig. 11—The no-block pallet not only reduces materials and shipping costs due to its lighter weight but it also reduces warehouse stacking space required. Displayed are 25 each of both the block pallets and no-block pallets. The no-block pallets on the right require less than one-half the stacking space formerly taken by the block pallets.

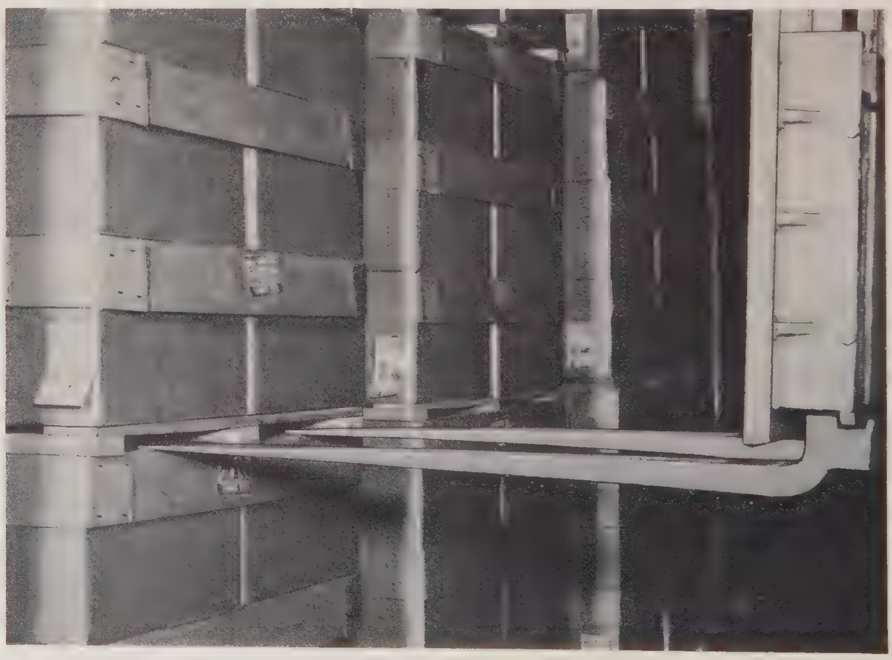


Fig. 12—Even with the slight clearance between unit-loads of only 1 in., fork trucks equipped with thin, tapered forks can handle the no-block pallet easily. Experience has shown that in shipping some 40,000 unit-loads on no-block pallets, there has been less pallet damage, better product protection, and safer warehousing.

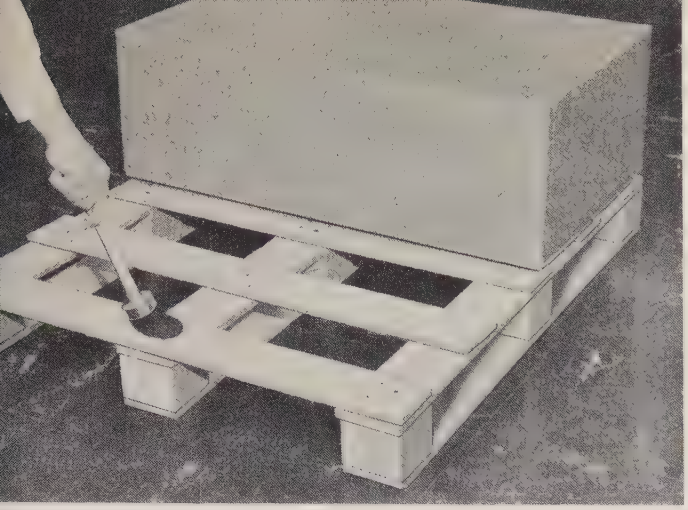


Fig. 13—Not only must the cartons be loaded to save costs in line handling, but they must also be secured as a unit to insure that the parts will arrive at their destination in an undamaged condition. For this purpose, spots of glue are brushed on the face boards of the pallet and the first layer consisting of two cartons is positioned. The packing of parts starts immediately since their weight helps to effect a good glue bond between the cartons and the pallet.

Fig. 16—This completed unit-load assembly is ready for identification and either warehousing or shipment to a General Motors plant. A sturdy, compact assembly such as this one represents low-cost, quality packaging.

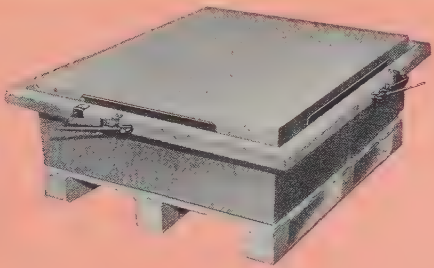


Fig. 14—After the first layer of cartons is packed, the glue (sodium silicate or water glass) is brushed in a 4-in. strip around the outside perimeter of both cartons. A common corrugated cover, scored, slotted, and having a 4 in. flange is placed over both cartons. A cam-actuated fixture is tightened in position around the cover flange to insure good contact while the glue is setting. Glued to the cartons, the cover acts to reinforce the top edges of the layer.

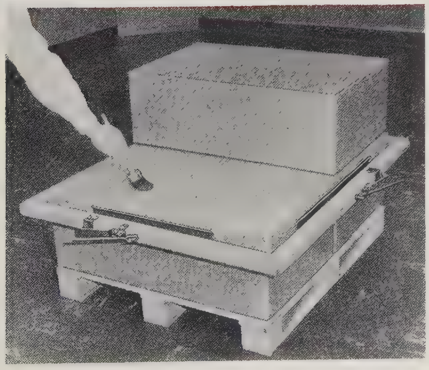


Fig. 15—To build the second layer of cartons the top cover of the first layer is spotted with glue and the next two cartons set in place. These cartons are packed, the common cover positioned, and the compression fixture applied as before to seal the cover flange to the cartons. These steps are repeated again for the third layer of cartons. Three layers or six cartons compose one unit-load.

Fig. 17—While palletized unit-loading has reduced costs in every instance where it has been tried thus far at the Ternstedt-Trenton plant, it has also aided inventory control, reduced warehouse space requirements, and reduced expenses in the Purchasing Department because now fewer different packaging items are needed, and these may be purchased in greater quantities. Former packaging methods would not have allowed pallets to be stacked in tiers as high as shown here due to low compressive strength and non-uniformity of size.

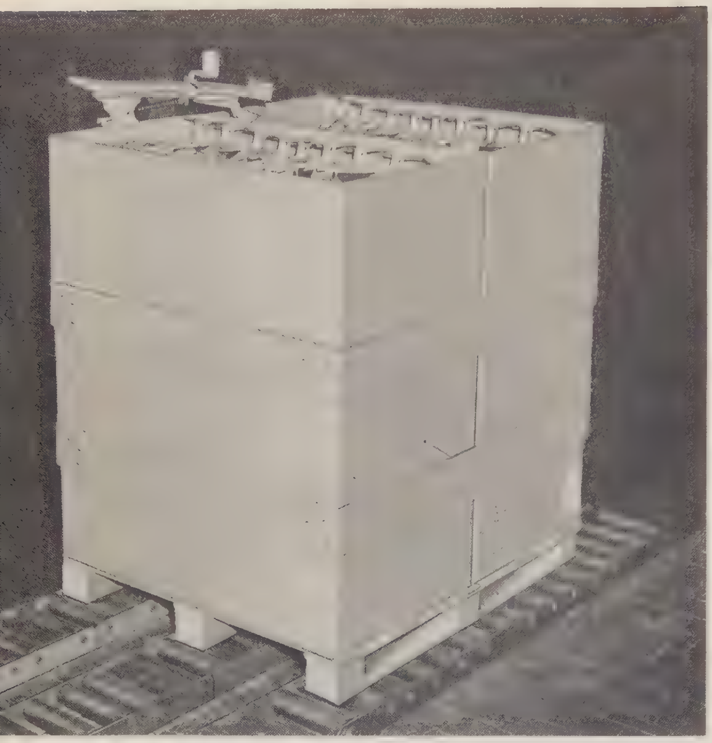


Fig. 18—In order to reduce the number of corrugated assemblies, it was necessary in some instances to rearrange the interior packing method. The first objective was cost reduction consistent with adequate product protection. The unit-load system functions best when parts are arranged so that they are self-supporting, thus adding strength to the unit. These seat adjusters, when placed in an upright position rather than flat in the carton, sustain more load thereby increasing the compressive strength of the unit. Seat adjusters previously were packed 12 to a carton; the new unit load consists of 216 seat adjusters with a gross weight of 1,000 lb. The change from individual carton packing to palletized unit-loads resulted in material and labor savings of 51 per cent in this case.

Fig. 19—Formerly packed 10 to a carton, these window control ventilators complete with glass are now packed in a unit-load weighing 985 lb which contains 210 ventilators. In this instance the change to palletized unit-loads reduced packing material and labor costs by 20 per cent.

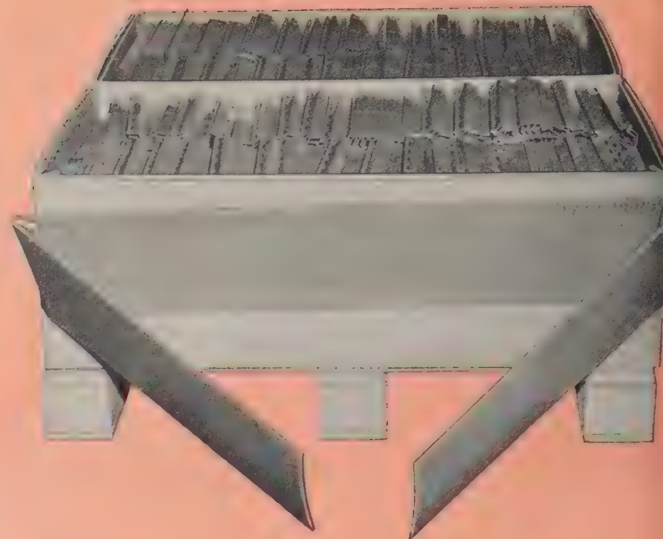


Fig. 20—Dense packing of heavy parts sometimes requires the use of a stitched liner to gain compressive strength. When this liner is placed around the inside walls of the carton, static loads in excess of 5,000 lb have been sustained.

Fig. 21—Since one of the objectives in palletized unit-loading is to package as many parts in each unit-load as possible consistent with efficient handling and adequate product protection, careful selection of packaging aids is essential. For example, 40-point smooth chipboard is used here to replace double face corrugated stock as separators for door garnish moldings. Both cartons shown contain 20 moldings. It is apparent that the chipboard separators permit a 25 per cent reduction in the length of carton used. Initial cost is lower and the chipboard surface is much less abrasive than the corrugated material. Chipboard, however, cannot safely replace corrugated board in all instances. Only in those cases where the parts are rigid enough to lend support to most surfaces of the carton is the chipboard justified. In such cases, however, at the Ternstedt-Trenton plant, the use of chipboard over corrugated resulted in a 29 per cent savings in material costs.

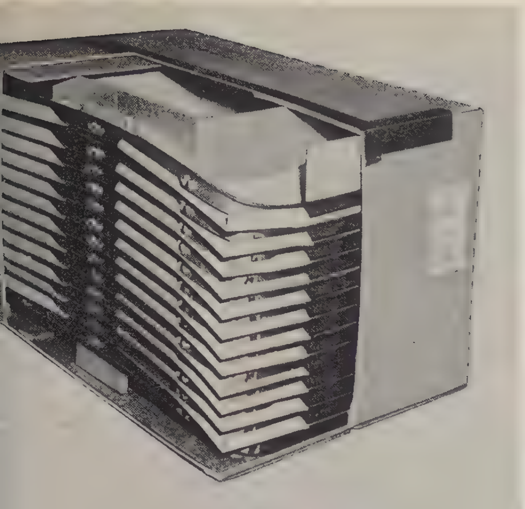


Fig. 22—Here is a case where die-cut chipboard is used to separate U-shaped, painted moldings because chipboard easily bends to follow the contour of the molding. The rectangular corrugated insert in the center bridges the inner carton flaps, greatly adding to the carton's compressive strength.

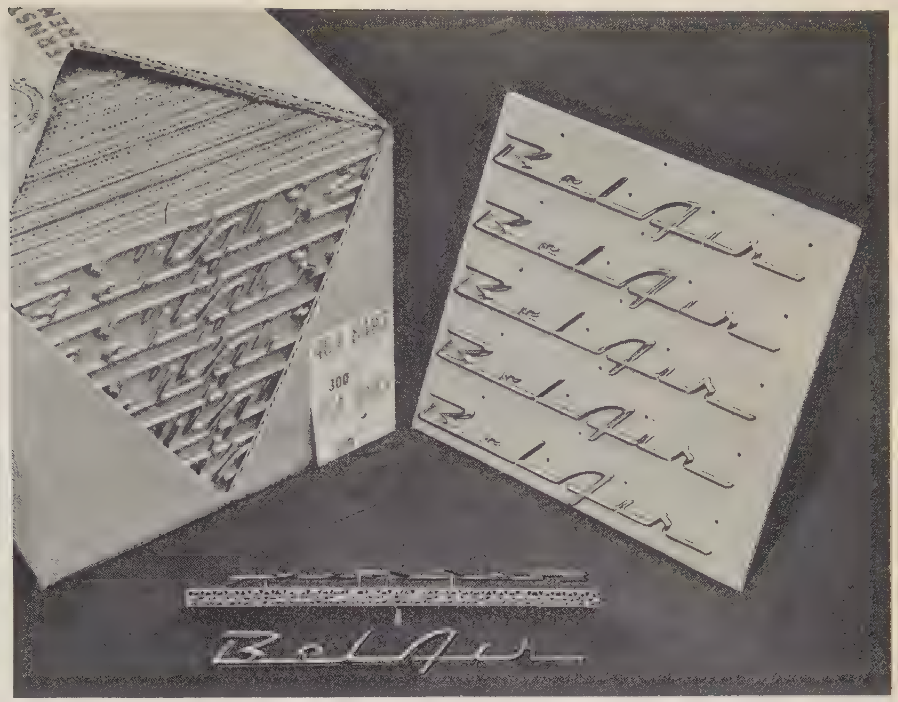


Fig. 23—Another example of an interior packaging aid is the built-up pad. Previously, Chevrolet Bel Air ornaments were wrapped in paper and then packed in cartons. Considerable damage resulted to projecting studs and to the bright chromium finish. The present method makes use of a corrugated pad which is die-pierced to receive the studs on the ornament. The pad not only provides protection to the studs and chromium finish but also acts as a carrier in manufacturing and assembly operations, thus making the final packing operation simpler and faster.

Fig. 24—Sometimes paper bags are the answer to a packaging problem. This corkscrew-type, stainless steel part is typical of those which cause the packaging engineer greatest concern. After experimenting with paper tubing, corrugated board, and various other types of board, the problem of 100 per cent finish protection was best solved by using a machine glazed, 25-lb test kraft paper bag.

Fig. 25—Certain parts are well suited to a method of packaging known as horizontal-vertical pad placement. This consists of placing corrugated or chipboard separators between the parts which are placed horizontally in the carton. Each vertical stack is protected from the next by a piece of double-face corrugated material which also adds to compressive strength.

Fig. 26—A view of the Ternstedt-Trenton plant shipping warehouse taken a few years ago shows how individual cartons were formerly used to package body hardware parts. The greater amount of manual handling necessitated by this type of packaging meant higher labor costs.

Fig. 27—The same warehouse as it appears today illustrates many advantages of palletized unit-loads, for example, more compact tiering to give better utilization of space and more orderly appearance of the stacks.

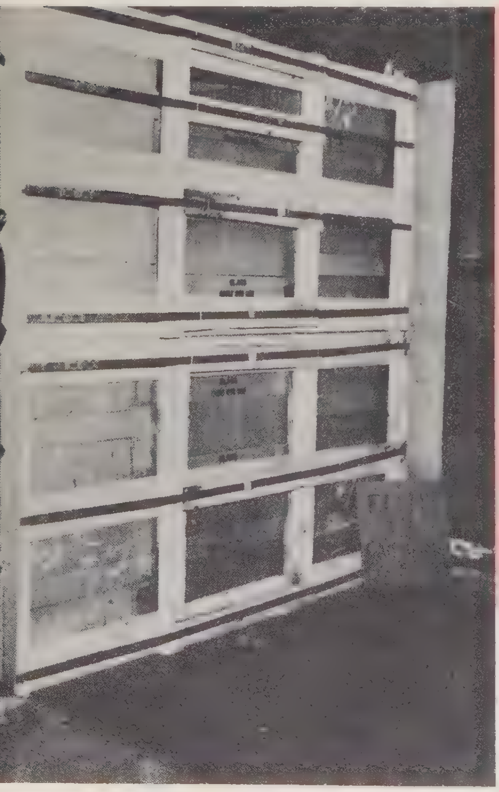


Fig. 28—The best designed package is ineffective unless it is properly braced in the carrier used to transport the material to its destination. A conventional freight car, for example, requires the use of dunnage—wood and steel straps used to secure cargoes (left). To reduce car loading costs as well as damage in transit, the Ternstedt-Trenton plant uses what are known as equipped cars (right). Special load bracing devices built into the car as shown hold the cargo firmly in place without loss of space. Currently, the Division is cycling 73 equipped cars representing slightly less than fifty per cent of its monthly freight car requirements, and efforts are being made to secure more cars of this type.

The Manufacture of Planet Pinions

By WALTER B. HERNDON
Detroit Transmission
Division

In a planetary gear set, the pinions are the vital members

The Hydra-Matic automatic transmission accomplishes torque change between the engine and rear wheels of a vehicle by means of gearing. The principal component of the gearing system is the planetary gear assembly, consisting of a central sun gear, planet pinion gears mounted in the planet pinion carrier, and a ring gear. For quiet, smooth operation precision-made gears are a necessity, particularly in the case of the planet pinion gears. The Detroit Transmission Division of General Motors produces some sixty thousand of these high quality pinion gears each day in order to manufacture the various models of the Hydra-Matic transmission used on passenger cars and trucks. Such a task requires close co-ordination between design, processing, manufacturing, metallurgy, and inspection.

FUNDAMENTALLY, the purpose of any automotive transmission is to change the torque-speed ratio between the engine and the rear axle. This torque multiplication can be accomplished in different ways—electrically, hydraulically, mechanically, or by combinations of these three. The Hydra-Matic automatic transmission has always accomplished torque change by the use of gearing. The transmission consists of a fluid coupling and three planetary gear sets providing four forward speeds and reverse. The forward shifts are automatic and vary with car speed and the wishes of the driver as expressed through pressure on the accelerator pedal. The relatively low cost, light weight, and the inherent high efficiency of gearing were the main factors which led to the decision to use gears. In most Hydra-Matic models there are 23 precision-made gears. These include internal or ring gears, sun gears, pinion gears, pump gears, speedometer drive gears, and starter gears. Of these, the most important perhaps is the small pinion gear. There are nine to twelve pinions used in each Hydra-Matic automatic transmission, depending on the model. At the present rate of Hydra-Matic production, more than sixty thousand pinion gears are made daily. Since the planet pinion is the most important member in a planetary gear set from the standpoint of quiet, smooth operation, it will serve to illustrate many of the design, metallurgical, manufacturing, and inspection problems that arise in large-scale precision gear production.

The Hydra-Matic automatic transmission is manufactured by the Detroit Transmission Division of General Motors at its facilities at the Willow Run Plant, about thirty miles west of Detroit. This Plant, one of the largest in the world, has more than two million square feet of floor space used for the production of more than six thousand Hydra-Matic automatic transmissions a day.

To produce some sixty thousand planet pinions daily is a task which requires the efforts of a well co-ordinated team. The principal parts of the team are: (a) the Product Engineering Department directed by the chief engineer, whose job it is to co-ordinate all the engineering activities necessary for the design and testing of the gears; (b) the Manufacturing Department under the direction of the works manager, who is responsible for the machines, the tools, and all the facilities that are required in the actual manufacture of the product; and (c) the Inspection Department headed by the chief inspector, whose responsibility is to see that every gear installed in the transmission meets the engineering specifications for dimensions and finishes.

Design Considerations

The pinion is the most important member in a planetary gear set. It is loaded on both sides of its teeth under

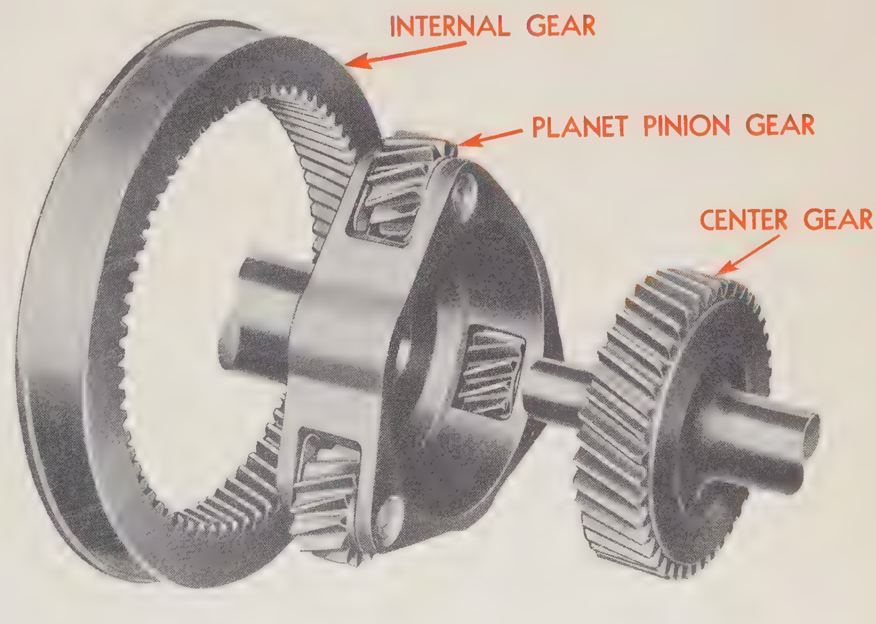


Fig. 1—To insure smooth, quiet operation of a planetary gear set the pinion gears must be accurately spaced on a circle concentric with both the sun and ring gears.

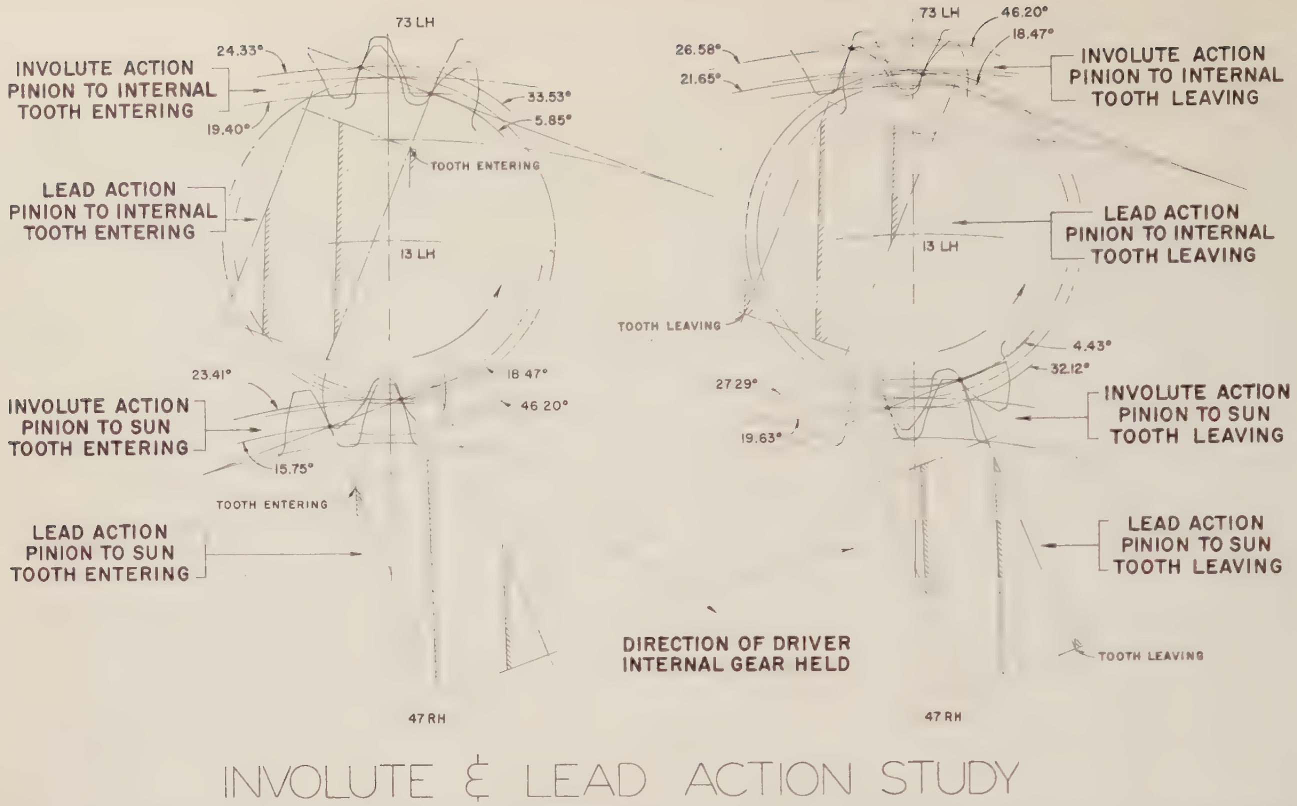


Fig. 2—This gear action layout shows the bearing path of each tooth against its mate on the meshing gear as the tooth enters and leaves mesh. All points on this path can be scaled off the layout or can be found by calculation. Usually, they are designated by degrees roll from the base circle.

both drive and coast conditions. In a three-pinion planetary gear set there are six pitch points which are the only possible sources of noise and tooth failure. While a set of pinion gears affects all six pitch points, the internal gear as well as the sun gear are each concerned with only three of these points (Fig. 1). A precisely made set of pinions will allow the use of internal and sun gears having wider tolerances on lead, lead variations, involute, and involute variations.

The planet carrier must keep the pinion gears properly spaced on a circle concentric with the base circles of the internal and sun gears. Also, the carrier must provide a good bearing for each pinion. This bearing must be in a common plane with the carrier axis and parallel to it. Any deviation in this respect will initiate lead errors between the pinion and its two mating gears.

The importance of the pinion bore cannot be overemphasized. An oversized bore will produce a condition similar to off-spacing of the pinion. A bore 0.0005 in. oversized will allow the pinion to float on a center 0.00025 in. ahead of the loaded pinions. An oversized or tapered bore will also permit the pinion to tilt. The end thrust on the pinion resulting from contact with the internal gear is theoretically equal and opposite to that exerted from contact with the sun gear. However, due to variations from the theoretical a certain amount of end thrust is usually present.

The pinion blank, as a rule, is much simpler than the ones used for the internal gear or the sun gear. It is basically an external gear with a precision bore. The pinion seldom requires a spline, bushing, or any other element which might complicate arbors and cause undue eccentricity, off-squareness, or complications in manufacture. For this reason, it seems that of the three gears in a planet, the pinion should be the easiest to make to precision tolerances.

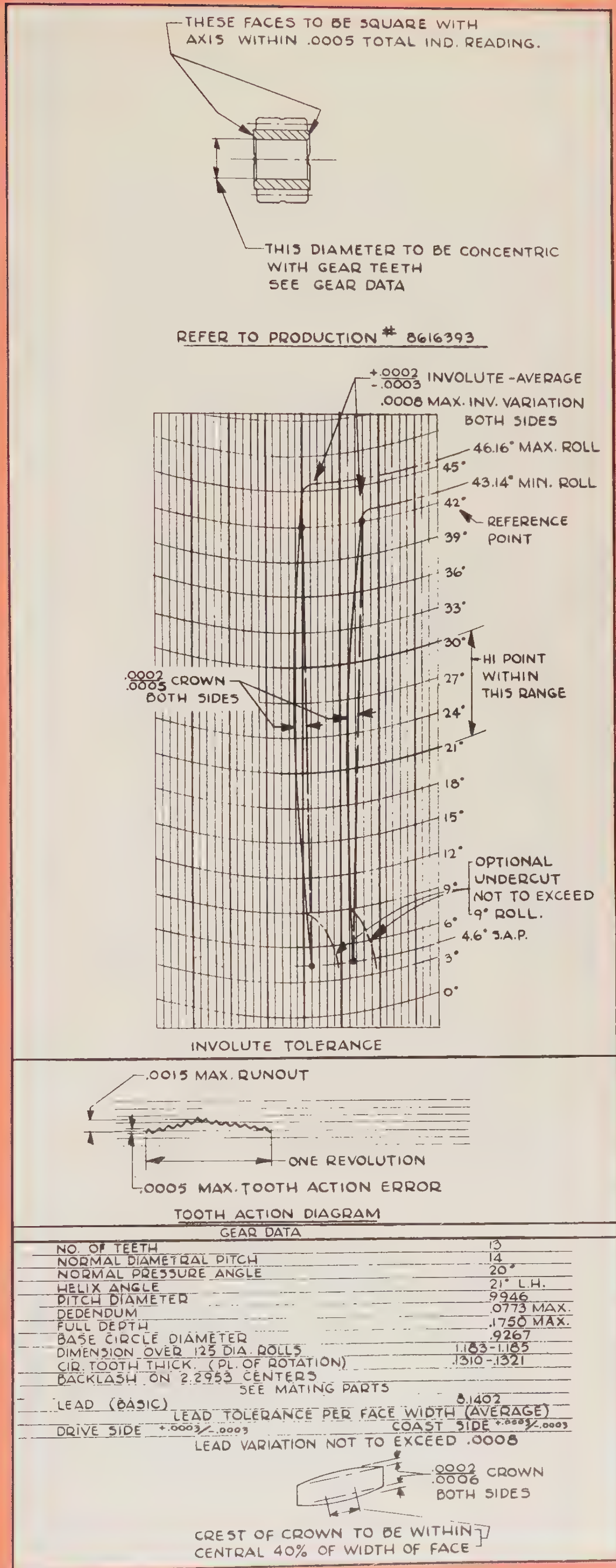
To determine the required lead and involute modifications it is necessary to make a gear action layout about ten times actual size (Fig. 2). This layout shows both lead action and involute action. Theoretically, perfect leads and involutes together with rigid mountings result in smooth mesh with neither angular acceleration nor deceleration when the teeth are entering or leaving mesh. Lead or involute interference on entering or leaving mesh can cause serious difficulty. Such interference in a gear set results in noise, shock loading, excessive wear, pitting, and sometimes tooth breakage.

In general, gear tooth form is modified from the theoretical to obtain long life and quiet operation. This is done on the gear tooth layout and checked by testing experimental pieces.

After this study has been made of the gears, manufacturing specifications are drawn up. They include:

- A contour trace of the involute (Fig. 3) as mapped by a machine called an involute checker. This includes the involute tolerance (average), the allowable involute variation, the limits on all possible hollows and crowns, the degree roll at the start of active profile, the degree roll at the crest of crown or hollow, and the degree roll at the minimum and maximum fall-off (inner diameter of internal gear or outer diameter of the external gear).
- A photograph of the gear
- A copy of a chart termed the "red line" (Fig. 3) which shows limits of tooth action errors (tooth kick) and eccentricity. In general, this is a composite check to show smoothness of roll against a master gear.

Fig. 3—(Right) This contour trace of the involute is mapped in the laboratory on a machine called an involute checker. It is recorded on the working drawings and becomes a part of the manufacturing specifications.



- Number of teeth
- Normal diameter pitch
- Normal pressure angle
- Helix angle—hand
- Pitch diameter
- Dedendum
- Full depth
- Base circle diameter
- Dimension over rolls
- Circular tooth thickness in the plane of rotation
- Backlash on specified centers with mating part
- Lead (basic)
- Average lead and lead variations.

Metallurgical Considerations

The planet pinions in the Hydra-Matic automatic transmission are manufactured from two types of steel—S.A.E. 5140-H and S.A.E. 5145-H. The reason for using two types of steel is to control the hardenability of the varying section sizes of the pinions to result in optimum gear life.

A typical analysis of the two materials is indicated in Table I. An analysis of regular S.A.E. 5140 is also shown to point out the chemical difference between the hardenability steel and normal S.A.E. steel.

The Jominy hardenability limits on the Rockwell "C" 50 point of the two steels are as follows:

S.A.E. 5140-H	*S.A.E. 5145-H*
J50 max. at 8/16	J50 max. at 12/16
J50 min. at 3/16	J50 min. at 4/16.

The hardenability limits are correlated to the quenching rates as used in Detroit Transmission's production practices, so that the core of the material will quench out to a fully martensitic microstructure throughout the section size.

Grain size of the "as received" material is specified to be "fine" or 5-8 McQuaid-Ehn Grain Size Specification Chart.

The "as received" material specifications of the stock require that it have a controlled microstructure consisting of a uniform blocky structure of fairly open lamellar pearlite and blocky ferrite with

Fig. 4—These micrographs are typical of planet pinions after heat treatment. Core structure is required to be a medium-fine tempered, acicular martensite with no free ferrite, while case structure is a fine tempered, acicular martensite with small, well scattered non-connected carbides.

some fine unresolvable pearlite. This structure has been determined to be the most satisfactory for the different machining operations performed. With this structure a hardness limit range of Brinell hardness number 187-207 is specified. Operations such as turning, form cutting, boring, and cutoff could use a softer material with increased feeds and faster speeds, but the shaping of the tooth form on the hobbing machines requires a higher hardness to manufacture the proper finish on the tooth form. Thus, the hardness and microstructure are economic compromises for all conditions to produce a quality pinion gear.

All new heats of steel are checked completely for all the aforementioned specifications prior to release for production usage. In addition to the base material on all new heats of steel, a trial sample lot of pinion gears is machined to completion and checked in the "green" state for all dimensional characteristics such as lead, involute, runout, hole size, *OD* (outside diameter) size, and *PD* (pitch diameter) size. These pinion gears are then heat treated in production equipment and rechecked for the same dimensional characteristics to establish the changes due to heat treatment. These changes are then compensated for in the "green" form so that the final tooth form will be within the blueprint specifications.

The planet pinion gears are heat treated in a completely automatic, pusher-type, tray-unit furnace line consisting of an atmosphere hardening furnace, quench setup, washing machine, and recirculated air temper furnace. The specifications call for a final Rockwell "C" hardness of 50-56 and a case depth of 0.005 in. to 0.010 in.

The hardening furnace is a gas-fired, radiant tube atmosphere furnace consisting of three heating zones. The temperatures are as follows:

Zone 1 — 1,450° F
Zone 2 — 1,525° F
Zone 3 — 1,500° F.

It has been determined that to obtain complete solution and proper case depth, a push cycle time of 10 min per tray load of approximately four hundred pinion gears resulting in a 2 hr total time in the furnace gives optimum control.

The atmosphere consists of an endothermic generator gas flowing at a rate of 900 cu ft per hr with natural gas as a carburizing medium flowing at a rate of 50 cu ft per hr. A typical analysis of the endothermic generator gas is as follows:

Carbon dioxide (CO_2) . . . . 0.0 per cent
Carbon monoxide (CO) . . . 20.7 per cent
Hydrogen (H_2) . . . . 38.7 per cent
Methane (CH_4) . . . . 0.8 per cent
Water (H_2O) . . . . 0.0 per cent
Nitrogen (N_2) . . . . 39.8 per cent
Oxygen (O_2) . . . . 0.0 per cent
Dew point . . . . +10° F to +25° F.

After the pinion gears have been austentized and the proper case depth acquired, they are quenched in hot oil at 300° F to 325° F. (Normal oil quenching temperatures are approximately 120° F to 150° F.) A hot oil quench method was established on the basis of distortion of the tooth form and the *ID* (inside diameter) of the pinion gear.

Much experimentation and development have been done to find the proper oil analysis and oil temperatures to obtain a minimum amount of distortion with a maximum quenching rate at an economical cost. The oil presently being used as the quench medium is S.A.E. 100 aircraft engine oil.

The pinion gears are quenched for 3 min in the hot oil so that they are completely uniform in temperature throughout the entire section. The pinion gears are removed automatically from the oil and allowed to cool slowly to room temperature (approximately 60 min to 70 min) so that completion of the transformation from the austenitic to the martensitic state will be gradual and uniform both inside and out. This hold-in-quench and slow cool procedure can be classified as a modified marquench process.

After transformation, the stock is washed to remove all quench oil and then tempered in a recirculating air furnace at 375° F for 1 hr. The tempering operation produces the required final hardness and relieves quenching stresses.

The Metallurgical Engineering Department requirements specify a final hardness of Rockwell "C" 50-56 and a hardness check requirement of Superficial Rockwell hardness "15N" scale 89-92 to insure a good surface hardness from the added case.

The Rockwell "C" 50-56 results in a pinion gear which has good impact properties for its particular usage, and the case hardness adds to the surface wearing properties of both the tooth form and the ID which acts as a needle bearing race.

Fig. 4 shows the microstructure of the heat treated pinion gear which is given a routine check in the laboratory as a control measure. The final microstructure of the core is required to be a medium-fine, tempered, acicular martensite with no free ferrite. The case is a fine tempered, acicular martensite with very fine, small pin-point-type, well scattered, non-connected carbides. It is this structure that results in an excellent wear-resistant surface.

Manufacturing Sequence

The sequence of operation in the production of the planet pinion is as follows:

(a) Rough gear blank produced from bar stock
(b) One side faced and hole sized
(c) Second side ground
(d) Gear teeth hobbed
(e) Gear teeth shaved
(f) Heat treatment
(g) Teeth chamfered and oil groove ground
(h) Hole honed.

CHEMICAL COMPARISON BETWEEN NORMAL AND HARDENABILITY S.A.E. STEELS

	S.A.E. 5140-H (Per Cent)	S.A.E. 5145-H (Per Cent)	S.A.E. 5140 (Per Cent)
Carbon	0.37-0.45	0.42-0.50	0.38-0.43
Manganese	0.60-0.95	0.60-0.95	0.70-0.90
Silicon	0.20-0.35	0.20-0.35	0.20-0.35
Sulfur	0.040 max.	0.040 max.	0.040 max.
Phosphorus	0.040 max.	0.040 max.	0.040 max.
Chromium	0.65-0.95	0.65-0.95	0.70-0.90

Table I—An analysis compares the chemical difference between a normal S.A.E. 5140 steel and the hardenability steels S.A.E. 5140-H and S.A.E. 5145-H. Hardenability steels are purchased with guaranteed hardenability limits, while the normal S.A.E. steels are purchased to chemical specifications only.

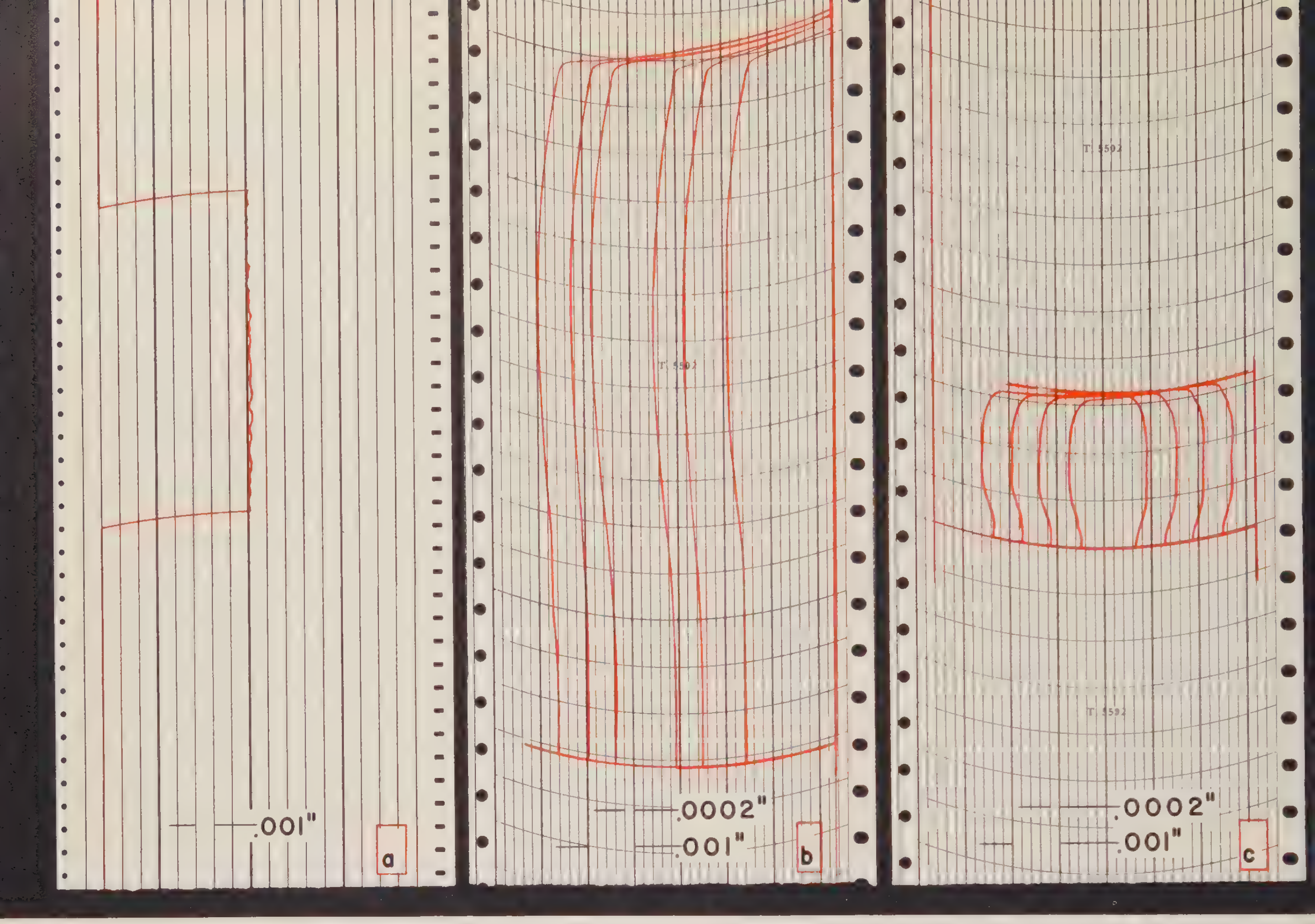


Fig. 5—Samples from the gear hobbing machines are sent to the gear laboratory at regular intervals during the production run. There they are checked on precision instrumentation for concentricity and tooth action (a), lead (b), and involute characteristics (c).

Blanks are cut in automatic screw machines of which there are 198 at the Willow Run Plant. Operations performed are form, turn OD, face, drill, ream, breakdown, and cutoff. Many blanks are produced on double cutoff machines that have a capacity of 160 gear blanks per hour.

Precision boring and facing machines are used to bore, face, and chamfer the hole in the blank. These machines have four spindles which operate two at a time. The tools for each spindle are held in one tool holder to assure maximum accuracy. The bore must be held to a 0.0003-in. tolerance and the face must be held square to the bore within 0.0002-in. accuracy. The finish on the face must be held to 50 microinch maximum, and the finish on the bore also must be held within 50 mircoinches to permit gaging of the parts with an air gage. The bore is checked for size, taper, and out-of-round condition 100 per cent. Bore faces are checked for squareness on each station at least twice a shift. After each lot of stock is inspected, it is placed on a belt conveyor which carries it to the rotary surface grinders.

The next operation on the blanks is to grind the unfinished face on rotary surface grinders. These machines are essentially large surface grinders having a rotary magnetic table which passes under the grinding wheels. At this operation the parts must be loaded on the rotary table with the finished face down. The machine must hold the ground face to within 50 microinches for finish and parallel to the turned face within 0.0005 in. A parallelism gage is used to check for size and parallelism continuously to determine when to dress the wheel or table. The finish is checked on the following inspection operation to determine when the machine must be corrected for finish. After the parts have been completed on this operation, they are put back into the original basket and placed upon a roller conveyor that carries them into the inspection area.

The inspection operation is performed next. At this point, the blanks are checked 100 per cent for bore size, taper, out-of-round condition, and squareness of faces. This is all done on air gages and the results tabulated to determine which items or machines need additional attention. The point cannot be stressed too highly that, to make a good gear, it is absolutely necessary to have gear blanks of highest quality. After the blanks have passed inspection the hobbing or gear tooth generating operation follows.

At the present time, hobbing is performed by both eight-spindle rotary machines and single-spindle machines. Since blanks are stacked four high on an arbor, it is easily seen why they must be

of unquestionable accuracy. One faulty blank would result in inaccurate machining of the other three blanks on the arbor.

The gears are checked for size with a pair of ball micrometers, and rolled for concentricity and tooth action against a master gear in a rolling fixture every two hours or oftener. Samples also are sent to the gear laboratory from all machines during the production run and after each time a hob is changed.

The gear laboratory inspection of hobbed gears is a continuous operation and consists of running the production gears against a master gear on a machine that charts the concentricity and tooth action of the gear being checked (Fig. 5). The hobbed gears also are checked for lead and involute characteristics after each hob change or whenever the gear chart indicates that a station may be out-of-limit. All hobbing limits are clearly indicated in written and blueprint form. Any time a machine is found approaching the extreme limit or is out-of-limit, it is shut down and corrected.

Following the hobbing operation the gears are shaved by rotary diagonal underpass shaving machines that automatically load and eject the pinions. It is necessary only to keep the chute leading into the machine loaded, the finished gears being removed by means of a ramp. The finished gears again are checked for size with ball micrometers and hand-rolled for concentricity and tooth action errors against a master gear. Samples from each shaving machine are submitted to the gear laboratory at least once per shift, sometimes oftener depending on the previous record of the machine and its cutting tool. After the shaving operation the pinions are washed prior to heat treatment.

Following heat treatment, the pinions are loaded into a semiautomatic machine that chamfers the acute angle side of the gear teeth and grinds oil grooves on both thrust faces of the pinion. This machine was designed by Detroit Transmission's process engineers especially for this operation. The pinions are loaded onto a ramp from which they are picked up by a conveyor which transports them into a basic rack and into contact with a grinding wheel that has been dressed, by crushing, into a hob-like form, except it does not have any gashes. After chamfering one side of the gear teeth the pinion then is turned automatically and the other side ground in the same manner. The pinions then are ejected from the machine onto a ramp which carries them to a large rotating wheel having circular spaces in its periphery. The pinions are picked up in these spaces and fed through two grinding wheels that grind the oil grooves into the thrust faces.

The final machining operation is to hone the bore to size within five ten thousandths of an inch with a finish of 10 microinches to 12 microinches. Bore finish is important because it affects pinion life. Shock loads on a gear having a rough bore finish will cause excessive tilt and needle bearing wear which would shorten the life of the pinion. Thus, every piece that comes off the honing machine is gaged for bore size and finish. Each honing machine is equipped with sizing rings which automatically compensate for stone wear. Each machine is capable of producing 300 pieces per hr.

After honing, the pinions are washed and inspected for nicks on the gear teeth. This is done by running each pinion against a master gear. Here the operator can pick out gears which are nicked, not fully shaved, have excessive pitch diameter runout, and have excessive variations from true lead, or involute form.

When the gears have passed the inspection for nicks, samples from each lot are then checked for bore size, taper, out-of-round condition, width between thrust faces, and finish in the bore and on the thrust faces. If defective pieces are found, the entire lot is inspected for those items found to be defective. Next, each pinion is inspected for tooth action, pitch diameter runout, and size. This is done on a hand-rolling fixture which rolls the pinion, metal-to-metal, against a master gear. Any variations are measured by an indicator. Pinions which feel rough even though the indicator shows them to be smooth are checked again on a gear analyzer. The analyzer is a rolling fixture which allows the pinion to roll in three planes with indicators showing the motion. By calibrating this fixture to gear laboratory standards, it is possible to establish close limits on acceptable or non-acceptable pinions.

Planet Pinion Movie Available to Educators

As a companion educational aid to this paper, a 16-mm sound, color movie entitled, "Manufacturing Planet Pinions," is available upon request by educators. Prepared by Detroit Transmission Division, the movie illustrates many of the steps in design, manufacturing, heat treating, and inspection which are described in this paper. Running time is 17 minutes. A copy of the film may be borrowed without charge upon request to:

General Motors Corporation
Department of Public Relations
Film Library
General Motors Building
Detroit 2, Michigan

Conclusion

To insure an efficient planetary gear set, all of the pinions must be of uniform high quality. A planetary gear set is designed in such a manner that three or more pinions mate with one sun gear and one internal gear. If one of these pinions is defective as to pitch diameter size, it would be forced to assume more or less of its proportionate share of the total load. In either case, the set would not function properly since each pinion must do its proportionate share of the work.

The satisfactory operation of a planetary gear set in a Hydra-Matic automatic transmission depends on (a) sound engineering design, (b) analysis of metallurgical requirements, and (c) close control of manufacturing and inspection operations. The production engineer must determine the proper lead and involute modifications for smooth mesh and absence of angular acceleration or deceleration. The metallurgical engineer must select the steel having optimum hardenability characteristics for the machining operations performed, and he must develop satisfactory methods for heat treatment and control of distortion. The Processing and Inspection Departments must maintain a close check on the accuracy of the gear cutting machines, as well as inspecting the gears for dimensions, finish, nicks, and tooth action.

When the gear manufacturer performs these tasks properly, the result is a quality pinion built for a quality set of gears which will run smoothly, quietly, and have long service life.

Manufacturing Engineers Develop Specifications for Resistance Welding Controls

By WILLIAM N. WITHERIDGE
General Motors
Manufacturing Staff

An electronic control panel for welding efficiency, quality, safety, and economy

General Motors engineers, working together as a team representing a variety of manufacturing experience and different points of view, have developed specifications for the performance of resistance welding control equipment.

Control panels built according to these specifications are compact, easy to install and maintain, and safe to operate and service (Fig. 1). They incorporate features that minimize the possibility of breakdown, thereby keeping welder productivity and efficiency at the highest possible level. Electronic timers provide accurate control of the welding cycle, giving a uniformly high quality of welds.

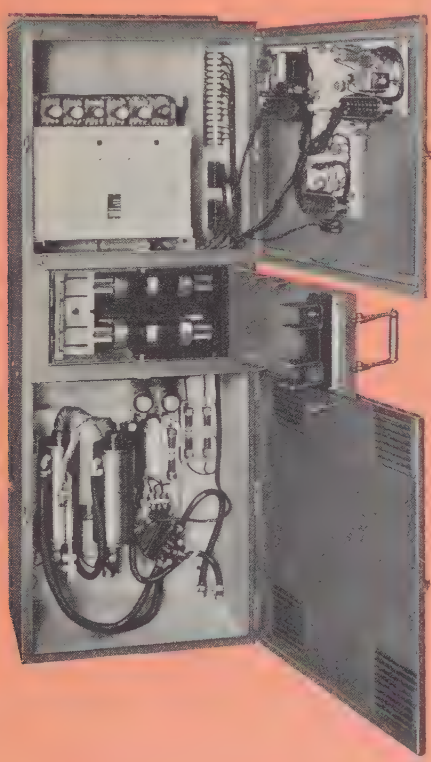


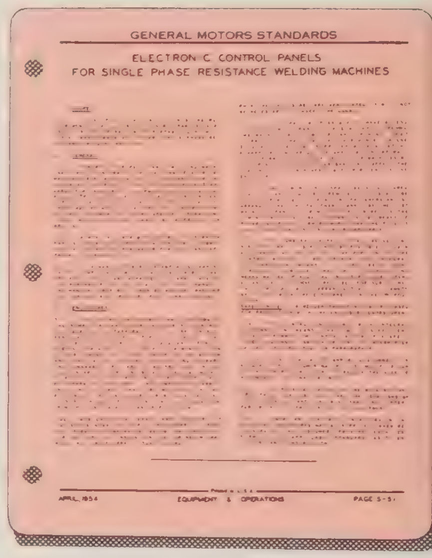
Fig. 1—Resistance welder control panels built to the newly developed General Motors specifications include the features of safety, space economy, reliability, and ease of service. This panel shows the disconnect switch in the center with the electronic timer in the upper enclosure and the ignitron contactor in the ventilated lower enclosure. Neither the timer nor the ignitron contactor section can be opened without first opening the disconnect switch.

Before this type of control panel, plants purchased timers, switches, and contactors separately and assembled them in place in various arrangements determined by the environment and by individual techniques of installation. Control equipment usually occupied more space than now is required by the new packaged unit, and production downtime for servicing was excessive.

The development of the welding control specifications is an example of how the engineering talents throughout the General Motors organization are brought to bear upon many such problems through the Inter-Divisional Committee Activities sponsored by the General Motors Manufacturing Staff and co-ordinated by the Production Engineering Section.

In this case, GM plant engineers, master mechanics, welding engineers, electrical engineers, and metallurgists collaborated in drafting performance specifications for resistance welding controls that contain the best thinking of these groups at the time of publication (Fig. 2). Improvements will be worked into the specifications as soon as their value and necessity are demonstrated.

During the writing of these specifications, equipment manufacturers were consulted to take advantage of their experience and to assure that the requirements would be commercially feasible. In applying the specifications, manufacturers are given as much freedom as possible in the details of design and fabrication.



GENERAL MOTORS STANDARDS

ELECTRONIC CONTROL PANELS
FOR SINGLE PHASE RESISTANCE WELDING MACHINES

Fig. 2—Members of faculties of engineering colleges and universities may obtain a complimentary copy of the General Motors specifications for resistance welding control panels upon request to:

W. N. Witheridge
Production Engineering Section
GM Manufacturing Staff
General Motors Technical Center
P. O. Box 27
Detroit 2, Michigan.

Diversification of manufacturing develops a range of experience in GM beyond that existing within a single plant or Division. By working together on problems of the kind here illustrated, production engineers in General Motors have an opportunity to acquire a more extensive knowledge of manufacturing, and are in a better position to keep their information up to date. Through these associations, many are stimulated to seek better ways to make high quality products at the lowest possible cost.

Some Special Problems in Connection with Inventions in the Chemical Field

By STANLEY E. ROSS
Patent Section
Central Office Staff

THERE are special problems in connection with inventions in the chemical field which do not arise with inventions in other fields. Inventions pertaining to metallurgy, ceramics, pharmacy, and biology, for example, are generally considered as within the "chemical" field.

These problems result principally from the fact that the Courts and the United States Patent Office recognize that chemical reactions are not entirely predictable and they must be determined by actual experimentation. In an early decision, the United States Supreme Court recognized the distinction between mechanical and chemical inventions in the following language:

> "Now a machine which consists of a combination of devices is the subject of invention, and its effects may be calculated *a priori;* while a discovery of a new substance by means of chemical combinations of known materials is empirical, and discovered by experiment."

In view of the recognized difference between chemical and other classes of inventions, the general rule that an inventor may claim his invention as broadly as is permissible in view of prior art provided the claim is not indefinite or functional has its limitations in chemical cases.

Limitations Affecting a Group of Like Materials

A claim in an application on an invention in the chemical field will not be allowed which attempts to cover an entire class of materials based on a teaching of a single material of the class. It is necessary to teach that other members of the class have the same general property which makes them effective for the intended purpose. A typical illustration of this situation occurs when an inventor discloses in his patent application the use of sodium chloride for a certain purpose. He will not be permitted to claim this feature broadly as by use of "metal halide" unless he shows or teaches a sufficient number of metallic chlorides, bromides, or iodides which can be used for the same purpose. A typical rejection in such case is that a claim is broader than the disclosure. This is a particular ground of rejection which quite frequently is applied to chemical cases.

In chemical cases a claim may not include within its terms materials which are inoperative for the inventor's purpose. There are numerous Court decisions in which a broad claim of this sort has been held invalid. This situation may arise where the inventor has found that several members of a relatively broad class of materials are satisfactory for his purpose. As a result of this relatively limited work the inventor may assume erroneously that all other members of the class are operative and, consequently, may make a broad claim which would encompass within its scope all members of the class. Should the patent be litigated with such a claim and the defense show that certain members of the broad class are inoperative, the broad claim may be held invalid.

In some cases the Patent Office will allow a special form of claim called a *Markush* claim. This type claim is applicable only to chemical cases and takes its name from the decision in the Patent Office in which the question first arose. In this type claim an artificial genus is defined in which the several members of the group are specifically recited. A typical Markush expression is "at least one material of the group consisting of A, B, and C." By this language the claim covers use of A, B, or C by itself or in a mixture with the other members. Originally, the Patent Office would not allow a claim to a natural genus and the artifically defined grouping in the same case. This is not true today and the applicant in a proper case may claim the invention both ways. Should the broader claim include inoperative members and thus be invalid, the applicant can fall back on the Markush-type claim

One problem: can a patent claim cover an entire group of materials?

including only those members found operative.

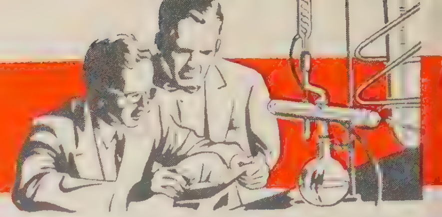
If the invention depends upon one or more critical condition, such as temperature, pressure, pH value, these must be included in the claim.

Operating Ranges Should be Specified by the Inventor

Other problems which are typical with chemical applications result from ranges in proportions of ingredients. It is of the utmost importance to have as exact information as possible concerning the extent of the ranges within which the invention is operative. Frequently, an inventor may work out certain proportions which are satisfactory and operative for his purpose, but without carrying his work far enough to determine the full extent of the ranges. Should an application be filed based solely on the narrower ranges with which the inventor had worked, there is a good likelihood that the Patent Office will not allow claims of sufficient breadth to cover other proportions of ingredients which may serve equally well. When there is both a broad range and a narrower preferred range of ingredients, both should be set forth in the application. In this case, should the Patent Office find a reference for the broad range, it still may be possible to obtain claims directed to the narrower range.

Another problem that arises frequently in connection with chemical cases is the use of trade-marks or trade names. The Patent Office presently permits use of these in patent applications if the composition of the material bearing the trade-mark or trade name is established by a definition in the patent application which is sufficiently precise and definite to be made part of a claim or if the composition of the material bearing the

Notes About Inventions and Inventors



trade-mark or trade name is well known and defined in the literature. Where the trade-mark or trade name has no definite or fixed meaning or the meaning is not otherwise given in the patent application, the examiner will object to the disclosure as insufficient. When trade-marks or trade names are permitted in patent applications the Patent Office makes every effort to protect the proprietary interest of the trade-mark owner by preventing their use in any manner which might endanger their validity as trade-marks.

The foregoing are some of the special considerations that apply to chemical patent applications. In addition, this type application is subject to the general requirements that apply to other classes of inventions.

On this and on the following pages are listed some of the patents granted to General Motors prior to June 30, 1955. The brief patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each patent.

Patents Granted

- **Leland D. Cobb,** **New Departure Division, Bristol, Connecticut, for a Demountable Seal, No. 2,706,123, issued April 12.* This invention relates to a demountable seal made from stamped-out elements which may be removably and easily secured in end-closing relation across the annular lubricant chamber of an antifriction bearing.

- **Howard M. Geyer,*** *Aeroproducts Operations of Allison Division, Dayton, Ohio, for a Fluid Pressure Actuator, No. 2,705,939, issued April 12.* This patent relates to a fluid pressure operated, self-locking actuator including bi-directional locking means which permit movement of the piston in only one direction at a time when released.

- **M. D. McShurley* and Donald G. Mahoney,*** *Delco-Remy Division, Muncie, Indiana, for Apparatus for Distributing Molten Metal to Molding Machines, No. 2,707,313, issued May 3.* The device claimed is a constant pressure distributing system for distributing molten lead or lead alloys from a main melting pot to a plurality of casting stations wherein the lead at each station is maintained at a constant pressure, irrespective of the quantity of lead in the main melting pot.

- **Frederick W. Sampson,*** *Inland Manufacturing Division, Dayton, Ohio, for a Steering Wheel, No. 2,707,406, issued May 3.* This patent relates to a steering wheel assembly having a horn blowing ring which forms a portion of the steering wheel rim while being capable of axial movement relative thereto.

- **Edward P. Harris* and Frederick W. Sampson,*** *Inland Manufacturing Division, Dayton, Ohio, for a Flexible Tubing, No. 2,707,490, issued May 3.* This invention relates to a defroster-type hose formed of spirally wrapped rubber tape which may be bent in a sharp curve. The tape has a reinforcing wire embedded therein to prevent inward collapse of the hose.

- **Edward P. Harris* and Frederick W. Sampson,*** *Inland Manufacturing Division, Dayton, Ohio, for a Flexible Tubing, No. 2,707,491, issued May 3.* This invention relates to a defroster-type hose which is formed of spirally wrapped rubber tape. The hose is designed to be bent to a sharp curve and has a plurality of reinforcing elements embedded therein which will prevent inward and outward collapse of the hose.

- **Edward P. Harris* and Frederick W. Sampson*,** *Inland Manufacturing Division, Dayton, Ohio, for a Flexible Tubing, No. 2,707,492, issued May 3.* This invention relates to a wire-reinforced defroster-type hose which is formed of spirally wrapped rubber tape. The hose walls are shaped to present a smooth inner surface when the hose is bent into a sharp curve.

Contributed by

Patent Section

Central Office Staff

- **Orson V. Saunders,** *Frigidaire Division, Dayton, Ohio, for a Refrigerator Door, No. 2,708,294, issued May 17.* This invention relates to locking a molded plastic door panel to a metal panel in a manner whereby the plastic panel can expand and/or contract relative to the metal panel, under temperature changes, without becoming warped or bowed.

  Mr. Saunders is supervisor of the major product line in the Household Engineering Department at Frigidaire. Employed as a senior detailer in May 1936, he was promoted through the positions of layout draftsman, designer, senior layout man, experimental engineer, project engineer, senior project engineer, and section engineer to his present position.

- **Robert L. Camping* and Robert C. Treseder,*** *Aeroproducts Operations of Allison Division, Dayton, Ohio, for a Balancing Means for a Propeller Blade Assembly, No. 2,708,483, issued May 17.* This patent relates to a propeller blade assembly wherein horizontal and vertical balancing are accomplished by removable weights that are accessible exteriorly thereof.

- **Arthur V. Lander, Louis W. Gomm, and Nelson J. Smith,** *Frigidaire Division, Dayton, Ohio, for a Refrigerator Cabinet Breaker Strip, No. 2,708,529, issued May 17.* This patent relates to the construction of an insulated breaker strip between inner and outer refrigerator cabinet metal walls which strip can be tightly locked to the walls against removal therefrom.

  Mr. Smith serves as chief engineer of Frigidaire Division, GM France. His 27-year career with GM began with Frigidaire in Dayton, Ohio, as an apprentice

engineer. Subsequent assignments spanned test work and product development of air conditioning and commercial refrigeration products. In 1946 he was assigned to the Overseas Operations Division as process engineer and in 1948 became chief engineer of Frigidaire Division, GM Limited in England. He was appointed to his present position in 1951. The University of Cincinnati granted him the B.S. degree in mechanical engineering in 1928. Mr. Smith's development efforts have resulted in 15 patents in the field of refrigeration and air conditioning.

Mr. Lander is no longer with the Division.

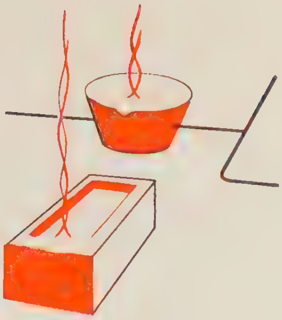
Mr. Gomm is no longer with the Division.

• **George C. Pearce,*** *Frigidaire Division, Dayton, Ohio, for a Domestic Appliance, No. 2,708,709, issued May 17.* This patent is for a wall mounted baking oven provided with "French doors" both of which open and/or close by a force applied to one of the doors.

• **Herbert H. Black and Roger D. Wellington,** *Diesel Equipment Division, Grand Rapids, Michigan, and Detroit Diesel Engine Division, Detroit, Michigan, respectively, for a Diesel Engine Control System, No. 2,708,919, issued May 24.* This patent covers a system of pneumatic devices responsive to blower intake and output pressures of a supercharged Diesel engine for controlling the fuel supply so as to both govern the engine speed and prevent exhaust smoking.

Mr. Black is assistant chief engineer at Diesel Equipment where he is responsible to the chief engineer for product development of Diesel, automotive, and aircraft components. His work has dealt with Diesel testing and development since 1936 when he was experimental engineer with the GM Central Office Product Study Section. He was transferred to Detroit Diesel Engine Division in 1938 and to his present Division in 1949. He was graduated from General Motors Institute in 1933, after which he did experimental automotive testing at Cadillac Motor Car Division for three years.

Mr. Wellington is director of the Engineering Laboratory at Detroit Diesel Engine. He joined the Division in 1938 as a project engineer, and was promoted through the positions of chief project engineer, section engineer, senior engineer, and assistant director of the Laboratory until appointment to his present



position. Mr. Wellington holds the B.S.M.E degree from University of Rochester, earned in 1930. Prior to joining General Motors, Mr. Wellington served Eastman Kodak Company as laboratory assistant and the Westinghouse Electric Corporation in various engineering positions.

• **Frank C. Pearson,** *Buick Motor Division, Flint, Michigan, for a Valve Tappet, No. 2,708,917, issued May 24.* This patent covers angling the cam contact foot of a tappet so as to prevent continuous axial rotation which has been found to cause spalling in the case of certain foot materials.

Mr. Pearson serves as staff engineer for defense contracts with Buick Motor. He first joined General Motors in 1935 as a chassis engineer. During World War II Mr. Pearson worked on a number of defense projects, and currently he is concerned with the J65 turbo-jet engine. Mr. Pearson received B.S. degrees from Massachusetts Institute of Technology and from Harvard University in 1918. Mr. Pearson is a member of the Society of Automotive Engineers and has served on a number of its committees.

• **Lester M. Miller,** *Frigidaire Division, Dayton, Ohio, for a Deep Well Cooker with Lifting Arrangement on Container, No. 2,709,-215, issued May 24.* A deep well cooker of an electric range has a container, the bottom of which is provided with feet forming circumferentially extending lifting hooks which, by a limited rotation of the container, engage the heater in the bottom of the deep well. Thereby the heater may be lifted, with the assistance of a spring, to the top of the well for use as an ordinary surface heater.

Mr. Miller is a junior engineer in Frigidaire's Engineering Department. He began as an inspector in 1948 in the Inspection Department. A year later he was promoted to process inspection. In 1952 he transferred to the Patent Section where he remained until July of this year, at which time he returned to Frigidaire. Mr. Miller's assignments have involved both special projects design and visual statistical aids. He attended the Dayton Art Institute, the Art Academy of Cincinnati, and the Central Academy of Commercial Art in Cincinnati, Ohio.

• **Edwin J. Miller and Richard S. Gaugler,*** *Frigidaire Division, Dayton, Ohio, for an Electric Motor, No. 2,709,228, issued May 24.* This invention relates to a moisture- and dust-proof hysteresis-type fractional horsepower motor having a rotatable cup shaped outer shell which is made of plastic and supports a band-type armature.

Mr. Miller is a physicist in Frigidaire's Engineering Department. His investigations are directed toward research and future product engineering developments. Allegheny College, Meadville, Pennsylvania, awarded him the B.S. degree in 1950 and two years later further study at University of Delaware earned him the M.S. degree. Mr. Miller's professional associations include membership in Sigma Pi Sigma (physics honorary society) and the American Physical Society. This is the first patent granted as a result of Mr. Miller's product development efforts.

• **William J. Foster and John R. Gretzinger,*** *AC Spark Plug Division, Flint, Michigan, and Allison Division, Indianapolis, Indiana, respectively, for a Bellows Folding Machine, No. 2,709,950, issued June 7.* This invention relates to a machine for folding an oil filter bellows employing a power-driven linkage that supports and actuates a plurality of formers to crease a tube of filter material to form the folded bellows.

Mr. Foster is no longer with the Division.

• **Richard M. Dilworth,** *Electro-Motive Division, LaGrange, Illinois, for a Cooling and Ventilating System for Generating Electric Locomotives, No. 2,709,967, issued June 7.* This patent has to do with the control of exhaust fans and air intake shutters for regulating the circulation of cooling air

*Inventors' names marked with an asterisk in this section have had their biographies published in a previous issue of Volume 2, GENERAL MOTORS ENGINEERING JOURNAL

through the cab and engine compartments of a Diesel-type locomotive.

Mr. Dilworth, retired, served for a quarter of a century as chief engineer of Electro-Motive. Mr. Dilworth has been deemed largely responsible for the Diesel replacing the steam locomotive. The son of a Presbyterian missionary working among the Indians in Oregon, his formal education was non-existent. Yet he rose to chief electrician in the U.S. Navy, and from construction machinist to engineer with General Electric. He participated in development of gasoline-electric rail cars, and constructed electric projects in the Phillipines. In 1926 he became chief engineer at Electro-Motive where he directed the application of the internal combustion engine to train propulsion until his retirement.

• **Howard H. Dietrich, Clarence H. Jorgensen,* and Willard T. Nickel,** *Rochester Products Division, Rochester, New York, AC Spark Plug Division, Milwaukee, Wisconsin, and Rochester Products Division, respectively, for an Engine Controller, No. 2,710,522, issued June 14.* This patent relates to a device for controlling the intake or manifold pressure of an aircraft engine and the control is effected in part by movement of the throttle valve to different positions and in part by controlling the supercharger speed. The same pressure selecting device which selects the pressure to be maintained determines the positioning of the throttle and also controls the setting of the waste gate of the supercharger to determine the speed of the latter.

Mr. Dietrich serves in the Engineering Department of Rochester Products. He is currently engaged in the study of aircraft engine fuel controls and carburetion, in which fields his work has resulted in approximately 25 granted patents. In 1926 Mr. Dietrich received the B.S.E.E. degree from Purdue University where he was elected to Theta Tau and Kappa Phi Sigma honorary societies. His technical affiliations include membership in the Society of Automotive Engineers and the American Institute of Electrical Engineers.

Mr. Nickel serves as a project engineer in the Engineering Department of Rochester Products, where he is primarily concerned with jet engine controls. He joined the Engineering Department of Buick Motor Division as a layout man in 1922, and was promoted to product study in 1938. In 1939 he transferred to Allison Division, Indianapolis, as an installation engineer for automatic controls, and he assumed his present position at Rochester Products in 1945. Mr. Nickel's work has resulted in several patent applications.

• **John M. Wetzler,*** *Allison Division, Indianapolis, Indiana, for Combustion Chamber Fairing, No. 2,711,072, issued June 21.* This patent relates to a cannular-type combustion chamber for a gas turbine engine and features the use of flow divider plates positioned between adjacent burners for simulating the action of individual combustion chambers.

• **Bernard E. Frank and Frederick C. Cummings,** *Rochester Products Division, Rochester, New York, for a Tube Bending Machine, No. 2,711,204, issued June 21.* This patent relates to a tube bending machine for forming serpentine sections of tubing and is an improvement on patent No. 2,565,940, the apparatus having a somewhat simplified and superior apparatus for performing substantially the same function as performed by the earlier machine.

Mr. Frank is senior engineer in the Tubing Engineering Department of Rochester Products. He received the civil engineering degree from Ecole Speciale D'Inginieur Technicien, Charleroi, Belgium, in 1939. Originally employed as a senior designer at Rochester Products in 1945, Mr. Frank was promoted to senior engineer in 1949 and to senior engineer in charge of tubing fabrication engineering in 1951. His work has resulted in 11 patents. He is a member of the American Society of Mechanical Engineers.

Mr. Cummings is a process engineer in the Process Development Section of Rochester Products. He was originally employed as a tool engineer in 1941. In 1948 he was made a junior engineer and in 1951 he was promoted to his present position. His projects include design and development of tubing process equipment, leading to this patent. Mr. Cummings studied tool engineering at the Rochester Institute of Technology. He is a member of the American Society of Tool Engineers.

• **Carl J. Bock,** *GMC Truck & Coach Division, Pontiac, Michigan, for a Motor Vehicle, No. 2,711,222, issued June 21.* This patent relates to means for driving the front wheels of a four wheel drive truck. The front wheels are driven through an overrunning clutch at a speed slightly slower than the rear wheels. The front wheels normally roll freely, but automatically become driving wheels if the rear wheels slip.

Mr. Bock, resident consulting engineer, served as chief engineer of GMC Truck & Coach from 1947 to 1955. He attended Iowa State College, majoring in mechanical engineering. In 1925, Yellow Cab, Yellow Coach, and General Motors Truck Company amalgamated and Mr. Bock was placed in charge of truck design and development. His technical affiliations include the S.A.E. and the Engineering Society of Detroit.

• **Maurice A. Thorne,*** *General Motors Engineering Staff, GM Technical Center, Detroit, Michigan, for a Brake with Hydraulic Line Seal, No. 2,711,229 issued June 21.* This patent relates to a hydraulic line seal disposed in the brake line across a juncture between the wheel spindle and a brake spider supporting the shoes.

• **Max Ephraim, Jr. and Robert I. Traver,** *Electro-Motive Division, LaGrange, Illinois, for a Fuel Cutoff and Reset Valve Operable from Plural Positions, No. 2,711,303, issued June 21.* This patent covers an inaccessible safety fuel valve between the fuel supply and engine of a locomotive closable from a plurality of remote positions which can be reset without gaining access to the valve itself.

Mr. Ephraim is locomotive section engineer in Electro-Motive's Engineering Department. His first position with that Division in 1939 was that of draftsman. Two years later he progressed to engineer-in-charge, industrial installations. Promotions followed to project engineer,

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

equipment design (1946), equipment engineer (1950), and his present title (1955). Mr. Ephraim directs the activities of the Locomotive Section which includes both locomotive and non-locomotive product design. He was granted the B.S. degree in mechanical engineering in 1939 by Illinois Institute of Technology where he was elected to the honorary societies: Tau Beta Pi, Pi Tau Sigma, and Sphinx.

Mr. Traver serves as project engineer in the Engineering Department at Electro-Motive. He joined this Department in 1945 as a junior project engineer. In 1949 he was promoted to his present duties involving engineering development on engine lubrication oil filters, fuel filters, air filters and, more recently, a mobile highway trailer generating set. Mr. Traver is an alumnus of General Motors Institute, having earned the Bachelor of Mechanical Engineering degree there in 1947. This is the first patent resulting from Mr. Traver's applied design activities.

• **William C. Edmundson, William A. Fletcher,* and Charles A. Nichols,*** *Delco-Remy Division, Anderson, Indiana, for a Brush Rigging for a Generator, No. 2,711,491, issued June 21.* This patent deals with a brush rigging for a generator which rigging may be attached to the wall of a generator housing and wherein the brush may be assembled and disassembled from the holder without the necessity of removing the holder from the housing or disturbing any of the other brushes which may be in use at the time.

Mr. Edmundson joined Delco-Remy in 1934 after receiving the B.S.E.E. degree from Purdue University. He was assigned to the Product Engineering Department where he became an assistant section engineer 1943 and section engineer in 1949. Shortly thereafter, he was promoted to staff engineer, his present position. Mr. Edmundson was formerly in charge of design and development of 12-volt cranking motors and generators for the new V-8 high compression engine electrical systems.

• **Peter R. Contant,** *Delco Appliance Division, Rochester, New York, for an Electric Clock Motor Control System, No. 2,711,501, issued June 21.* This patent relates to an electric clock of the magnetic impulse type including a time delay reactive network for controlling the rate of flux decay upon opening of the energizing circuit.

Mr. Contant has served with Delco Appliance since 1926, when he was originally employed as a blueprint room helper. Regular promotions within the Engineering Department led to his present classification as senior project engineer in charge of the development and design of electric windshield wiper mechanisms. His previous major project work was on the development of Delco-Heat conversion oil burners and automotive electric clocks.

• **Kenneth C. Kernen, Ralph H. Mitchel, and Raymond E. Schwyn,** *AC Spark Plug Division, Flint, Michigan, for a Connector for Use on a High Tension Resistance Cable, No. 2,711,520, issued June 21.* This patent relates to a connector for providing a permanent electrical connection with an electrical conductor having a conductive core consisting of a material which is not adapted for soldering. The connector includes a long shank having a plurality of barbs that embed themselves in the conductive core for mechanically locking the connector in the electrical core of the conductor, so as to form an electrical connection therebetween.

Mr. Kernen serves as a mechanical engineer in the Manufacturing Development Department of AC Spark Plug. He first joined GM in 1929 as a layout draftsman with Buick Motor Division, and transferred to AC Spark Plug in 1933 as a kiln designer. In April 1955 he assumed his present position. Mr. Kernen was graduated from Michigan State University of Agriculture and Applied Sciences with the B.S. degree in 1920. He is a registered professional engineer in the state of Michigan.

Mr. Schwyn is a senior research metallurgist at AC Spark Plug. He was first employed as a metallurgist in 1939 after being graduated from Michigan State University of Agriculture and Applied Science with the B.S. and M.S. degrees. At present, he is engaged in spark plug electrode alloy development. Previous projects were in the field of temperature-sensitive magnetic materials and the development of electrodes for cold-cathode discharge tubes.

Mr. Mitchel has been with AC Spark Plug since 1929 when he was employed as a laboratory assistant. He is presently engaged in projects involving electron microscopy. Five patents have resulted from his previous work, in the fields of temperature-sensitive magnetic alloys, electronic tubes, and engine ignition. Mr. Mitchel earned the B.S.E.E. degree from University of Michigan in 1929.

Technical Presentations by GM Engineers

A new inflection to GM engineers' speaking activities was given during the summer through participation in the Conference for Engineering Educators, sponsored jointly by the Engineering and Manufacturing Staffs of the Central Office and co-ordinated by the Educational Relations Section.

Appearances before educational and student groups decreased considerably during the summer months but many requests for fall appearances are forthcoming. Principal speaking activities of General Motors Divisional personnel during this summer period involved participation in technical seminars and contributions to engineering courses of study.

Product Engineering

"Fluid Coupling Design" was the title of the paper presented by **V. C. Moore,** assistant staff engineer, Fluid Coupling Converter Development, Detroit Transmission Division, before the student body of the General Motors Institute, Flint, Michigan, on July 28.

Chevrolet Motor Division was represented at the Society of Automotive Engineers' Golden Anniversary's National West Coast Meeting held at Portland, Oregon. **Maurice Olley,** special assistant to the chief engineer-in-charge of suspension development, Research and Development Section, delivered a "Report on New Suspension on Commercial Vehicles" on August 15.

Dean P. Roberts, distributor sales representative—farm products in the Sales Department, Delco Products Division, described the techniques of "Grain Drying" before the McLennon Company Agricultural Worker's Counsel, in Waco, Texas, on July 8.

Manufacturing Processes and Facilities

A discussion on "Organization Analysis" was led by **William J. Purchas, Jr.** chief engineer, Diesel Equipment Divi-

sion, at a seminar of government leaders on August 16. This top-management seminar was held as part of the Ordnance Management Engineering Training Program at Rock Island Arsenal, Rock Island, Illinois.

On July 21, **John Reed**, product engineer in the Product Engineering Department, Fabricast Division, presented an investment casting film before the Kiwanis Club of Orleans, Indiana. This film was also presented and discussed by **Fred Carl**, director of engineering and inspection, Product Engineering Department, Fabricast, before the Rotary Club, Bedford, Indiana, on August 4.

General Engineering

David C. Apps, head of the Noise and Vibration Laboratory, General Motors Proving Ground, Milford, Michigan, contributed to a special noise reduction course as a member of the teaching staff of Massachusetts Institute of Technology in Cambridge, from August 22 through August 25.

Participating in an IBM-650 Seminar at Endicott, New York, on August 1 was **J. T. Horner**, supervisor, Engine IBM Calculation Group of the Aircraft Engines Operations of Allison Division. His presentation outlined the "Relative Programming for the IBM-650 Computer." Mr. Horner also presented "Present and Future Data Processing Installations" before the National Council of Teachers of Mathematics at Indiana University, Bloomington, Indiana, later in the month, on August 24.

1955 General Motors Conference for Engineering Educators

An important function of the General Motors educational relations program directed by **Kenneth A. Meade**, director of the Educational Relations Section of the Department of Public Relations, this two-week conference is held to orient engineering educators on the product and production activities of General Motors Corporation. As in previous conferences, **Charles A. Chayne**, vice president in charge of Engineering Staff, and **John J. Cronin**, vice president in charge of Manufacturing Staff, were conference chairmen and hosts to the

educators. Twenty-four engineering educator guests attended as representatives of colleges in Canada and in nearly all areas of the United States.

The conference was conducted in Detroit beginning July 10 and covered illustrated presentations by Divisional and Staff executives describing company policies and operations, supplemented by facilities inspection tours and individual plant assignments. At the end of the conference, the educators analyzed their observations in a final session and presented their conclusions to their conference hosts.

To offer an overall view of General Motors to the educators, the presentations covered such subjects as: organization of General Motors, technical personnel activities, and production techniques. Inspection trips in the Detroit area included the General Motors Research Staff, the Process Development Section of the Manufacturing Staff, and the Engineering Staff—all General Motors Technical Center activities—followed by trips to the Proving Ground at Milford, Michigan, and the General Motors Institute in Flint.

On July 11 **William F. Andersen**, director of the Budget and Procedure Section, spoke on "The Organization of General Motors." Other speakers during the day were: **Louis C. Goad**, executive vice president, who discussed "Engineers in Designing and Manufacturing;" **Charles A. Chayne**, vice president in charge of the Engineering Staff, who described "Engineering in General Motors;" **John J. Cronin**, vice president in charge of the Manufacturing Staff, who talked on "Manufacturing in General Motors;" **Paul Garrett**, vice president

Requests may be directed to the Educational Relations Section for assistance in obtaining the services of GM engineers to speak before engineering classes or other student groups.

in charge of the Public Relations Staff, who spoke on "The Working Engineer and Public Relations;" **Edwin L. Yates**, director of college and university relations, Personnel Staff, who described "General Motors Recruitment and Training Programs;" and **George A. Jacoby**, executive director of the Committee for Educational Grants and Scholarships, who presented "General Motors Scholarship Plan" to the educators.

Before observing the facilities and equipment of the Proving Ground, the educators heard **H. H. Barnes**, director, describe the "Organization and Function of General Motors Proving Ground" on July 16.

During a second field trip to General Motors Institute on July 18, the group toured laboratory facilities and heard **Guy R. Cowing**, president, discuss "The Organization and Activities of General Motors Institute" and **Charles L. Tutt, Jr.**, administrative chairman, Fifth-Year and Thesis Programs, report on "Engineering Education at General Motors Institute." These speakers were followed by a panel discussion on selected areas of engineering taught at the Institute. The panel, which was moderated by **Harold M. Dent**, administrative chairman of the Cooperative Engineering Program, featured the following Institute Departmental members: **Earl D. Black**, Product Engineering Department, on "Engineering Drawing" **Erik H. Halvarson**, Product Engineering Department, on "Fundamentals of Engineering Design;" **Morris D. Thomas**, Science Department, on "Welding;" and **Joseph O. McGinnis, Jr.**, Industrial Engineering Department, on "Motion and Time Study."

At the luncheon during the G.M.I. visit, **John F. Gordon**, vice president of General Motors and executive in charge of the Body and Assembly Group, was the speaker on the topic "What Goes on Here."

At the dinner held on July 21 at the Park Shelton Hotel, the group was addressed by **Dr. Kenneth McFarland**, General Motors educational consultant and lecturer.

The final session of the conference held the following day was the one in which the educators summarized their observations of General Motors, terminating in a talk by Dr. C. Richard Soderberg, dean of engineering, Massachusetts Institute of Technology, who outlined the "Objectives and Problems of Engineering Education Today."

Solution to the Previous Problem:

Determine the Basic Design Specifications for a Ball Bearing Screw Assembly

By GEORGE A. WIDMOYER
Saginaw Steering
Gear Division

Assisted by Merle L. DeMoss
General Motors Institute

The rolling ball, screw, and nut each requires consideration

Each ball bearing screw assembly must be individually designed to meet specific load, space, and life requirements. Economies in design and production are realized when a standard screw which can be readily manufactured by existing tooling facilities is utilized for a particular application. When this occasion arises, the engineer must check to see if the standard screw design will fulfill rotational and strength requirements. If these requirements are met, then the basic design specifications relating to the ball nut are determined. This is the solution to the problem presented in the September-October 1955 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

THE ball bearing screw assembly, used as an actuator for extending and retracting an aircraft's wing flap, has a required screw rotation of 960 rpm and a 9,000-lb design load equally applied to the trunion-type ball nut (Fig. 1). To check the feasibility of utilizing the existing tooling setup, it was required to first determine whether the screw which would be produced would fulfill strength and rotational requirements.

Part (a) of the problem required the determination of the column strength of the screw as a check to see if the screw will withstand the design load of 9,000 lb. Considering the screw as a solid column having both ends pivoted or hinged, the column strength can be determined by applying Euler's formula as follows:

$$P = k\pi^2 \, E \, I \, / l^2$$

where

- P = collapsing load on the screw (lb)
- k = a constant depending upon the end conditions of the column. (For a column with both ends pivoted or hinged, $k = 1$.)
- E = modulus of elasticity of the steel screw (30×10^6 psi)
- I = least moment of inertia (in.^{4})
- l = length of the screw (65 in.).

The least moment of inertia for the solid screw having an effective diameter d of 1.4375 in. can be calculated as follows:

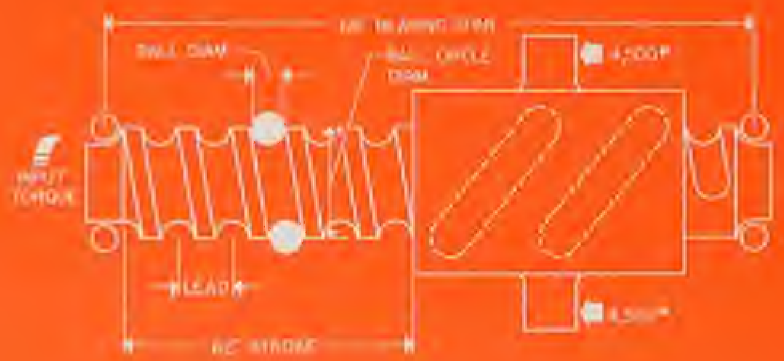


Fig. 1—A 9,000 lb load is applied equally to each side of the non-rotating ball nut to prevent a "cocking" action and to assure that the resultant force is along the longitudinal axis of the assembly. The assembly has a required screw rotation of 960 rpm. It is first necessary to calculate the critical speed and column strength afforded by the existing screw design to see if it will meet the required rotational and strength requirements.

$$I = \pi d^4 \, / \, 64$$
$$I = 3.1416 \, (1.4375^4) \, / \, 64$$
$$I = 0.2096 \text{ in.}^4$$

Substituting the calculated value for I into the previous equation for the collapsing load on the column gives:

$$P = 1 \, (3.1416)^2 \, (30 \times 10^6) \, (0.2096) / 65^2$$
$$P = 14{,}689 \text{ lb.}$$

The calculated value for the column strength indicates that the screw is sufficiently strong to withstand the design load of 9,000 lb.

Part (b) of the problem required the determination of the bore diameter. By revising the previously used Euler's formula and solving for I, the least

moment of inertia for the screw when subjected to the design load of 9,000 lb will be obtained as follows:

$$I = P\,l^2 / k\pi^2 E$$
$$I = 9{,}000(65)^2 / 1\ (3.1416)^2\ (30 \times 10^6)$$
$$I = 0.128 \text{ in.}^4$$

The moment of inertia for a cylinder having an outside diameter d_o and an inside diameter d_i is expressed as:

$$I = \pi/64\ (d_o^4 - d_i^4).$$

Substituting the calculated value $I = 0.128$ in.^{4} and the established value for the outside diameter $d_o = 1.4375$ in. into the previous equation and solving for d_i will give the bore diameter as follows:

$$d_i^4 = d_o^4 - 64\ I / \pi$$
$$d_i^4 = 1.4375^4 - 64\ (0.128)/3.1416$$
$$d_i = 1.135 \text{ in.}$$

Part (c) of the problem required the determination of the first critical speed of screw rotation as a check to see if the required rotation of 960 rpm is within a safe limit. Considering the screw to be a uniform shaft, the first critical speed can be determined by the following formula:

$$f = 31 / l^2 \sqrt{EI / w}$$

where

- f = first critical speed (revolutions per second)
- I = moment of inertia of the area of the cross section (in.^{4})
- l = span between bearings (in.)
- E = modulus of elasticity for the steel screw (30×10^6 psi)
- w = weight of screw material (lb per in. of length).

Substituting the values for E, I, and w into the previous equation and simplifying results in:

$$f = 80{,}000 \sqrt{d_o^2 + d_i^2 / l^2}.$$

The problem stated that the effective outside diameter of the screw can be assumed to be the root diameter of the screw (ball circle diameter minus one ball diameter). The effective outside diameter, therefore, is equal to 1.625 in. minus 0.1875 in. or 1.4375 in. The effective bearing span was stated as 68 in. Substituting the values for d_o, d_i, and l into the previous equation gives:

$$f = 80{,}000 \sqrt{1.4375^2 + 1.135^2 / 68^2}$$
$$f = 31.7 \text{ revolutions per second}$$
$$f = 31.7(60) = 1{,}902 \text{ rpm.}$$

This calculation shows that the required 960 rpm of the screw is 960/1,902 = 50.5 per cent of the critical speed, or well within a safe limit.

The answers obtained to parts (a), (b), and (c) of the problem indicate that the existing tooling setup can be used to manufacture the screw. It is now necessary to determine the basic design specifications for the ball nut.

Part (d) of the problem required the determination of the number of ball circuits and the number of turns of balls per circuit to be used in the ball nut. The length of travel of the ball nut along the axis of the screw was stated as 62 in. The lead of the screw, or the distance that the screw advances in one complete revolution, was stated as 0.36363 in. The screw, therefore, will rotate through 62/0.36363 or 171 revolutions per stroke. The travel of the nut through two strokes constitutes one cycle. The screw rotates, therefore, through 172(2) or 342 revolutions per cycle. The number of impacts per revolution for a 1.625-in. diameter ball circle with 0.1875-in. diameter balls was stated as 11.75. The number of impacts per cycle, therefore, is equal to 342(11.75) or 4,019. The required life of the ball bearing screw assembly was stated as a minimum of 12,000 cycles. The total number of impacts on the ball as it rolls between the grooves on the nut and screw will be equal to 4,019(12,000) or 48.228 million.

It is now necessary to determine the allowable load per ball for 48.228 million impacts. The problem stated that the life of a ball is inversely proportional to the cube of the load on the ball and that the allowable load per ball for the 0.1875-in. diameter ball for one million impacts is 116 lb per ball. The allowable load, therefore, on each ball for 48.228 million impacts is:

$$48.228 \times 10^6 / 10^6 = 48.228$$
$$\sqrt[3]{48.228} = 3.64$$
$$116 / 3.64 = 31.87 \text{ lb per ball.}$$

The applied load on the trunions is 9,000 lb. The allowable load for each ball is 31.87 lb. The number of balls required, therefore, is equal to 9,000/31.87 or 282. The number of balls required per turn can be determined by dividing the circumference of the ball circle diameter by the diameter of one ball as follows:

$$\pi(1.625) / 0.1875 = 27.2 \text{ balls per turn.}$$

The number of turns required is equal to 282 balls divided by 27.2 balls per turn or 10.4 turns.

The problem stated that a ball nut may contain 1, 2, or 3 circuits of 1½, 2½, or 3½ turns per circuit. From this it is evident that the use of a single circuit ball nut is not possible. When a ball nut of two circuits is considered, the maximum number of turns possible is 2 circuits times 3½ turns per circuit or 7 turns. The number of turns required, however, is 10.4. The use of a ball nut of 3 circuits of 3½ turns per circuit will give 10.5 turns, which satisfies the requirement.

Part (e) of the problem required the determination of the number of cycles through which the assembly can be expected to function without ball failure. The required life of the assembly was to be a minimum of 12,000 cycles. Using previous information, the expected life of the assembly can be determined as follows:

$$27.2 \text{ balls/turn} \times 10.5 \text{ turns} = 285.6 \text{ balls}$$
$$9{,}000\text{-lb design load}/285.6 \text{ balls} = 31.51 \text{ lb/ball.}$$

The allowable load for the 0.1875-in. diameter ball for 1,000,000 impacts is 116 lb per ball. Using again the previous statement that the life of a ball is inversely proportional to the cube of the load on the ball the life of the ball, in impacts, can be determined as follows:

$$116 / 31.51 = 3.681$$
$$3.681^3 = 49.88 = 49.88 \text{ million impacts.}$$

The number of impacts per cycle for a 0.1875-in. diameter ball was previously calculated as 4,019. From this, the expected ball life for the ball bearing screw assembly can be determined as follows:

$$49.88 \times 10^6 / 4{,}019 = 12{,}411 \text{ cycles.}$$

The expected life is more than the minimum required.

Part (f) of the problem required the determination of the input torque T required to drive the screw, having a lead L of 0.36363 in., under the design load P of 9,000 lb with an efficiency e of 92 per cent. The input torque required can be determined as follows:

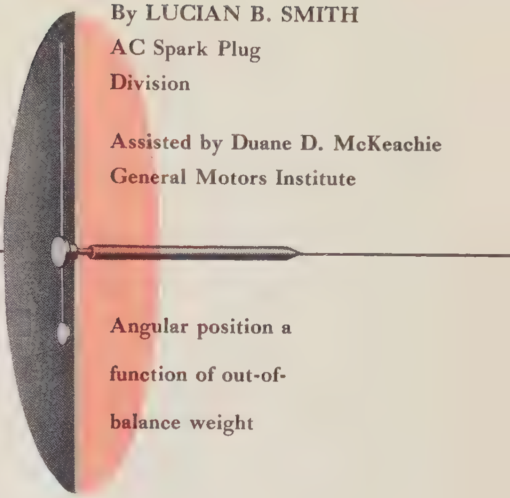
$$T = PL / 2\pi e$$
$$T = 9{,}000(0.36363) / 2(3.1416)\ (0.92)$$
$$T = 566 \text{ in.-lb.}$$

A Typical Problem in Engineering:

Determine the Angular Position of Two Punched Holes to Statically Balance a Speedometer Speed Cup

By LUCIAN B. SMITH
AC Spark Plug
Division

Assisted by Duane D. McKeachie
General Motors Institute



Angular position a function of out-of-balance weight

The function of the speed cup component of a speedometer assembly is to actuate the pointer which indicates the speed of a vehicle. This function is achieved by rotating a permanent magnet inside the speed cup which exerts a magnetic drag on the cup and, in turn, causes it to rotate and to actuate pointer movement. In order for the speed cup to function properly it must be statically balanced prior to placement in a speedometer. The static balance is achieved by punching three holes in the rim of the cup which removes a required amount of weight necessary to offset the cup's out-of-balance weight. In the actual punching operation, one hole is first punched on a horizontal centerline at right angles to the heavy side of the cup. The problem presented here is to determine the angular position at which the remaining two holes must be punched simultaneously to achieve static balance.

A SPEEDOMETER and tachometer indicate, through the use of a pointer and a face dial, the speed of a vehicle in miles per hour and engine revolutions, respectively. The section of a speedometer or tachometer which actuates the pointer is comprised of four components—a rotating magnet, a stationary field plate, a non-magnetic movable speed cup and spindle, and a hair spring attached to the speed-cup spindle (Fig. 1).

In operation, the permanent magnet, which is driven by a cable-casing assembly connected to a set of gears in a vehicle's transmission or to the generator shaft, crankshaft, or distributor shaft in the case of a tachometer, rotates clockwise within the speed cup. This causes a rotating magnetic field which exerts a pull or magnetic drag on the speed cup and causes it to rotate in the same clockwise direction. Attached to the end of the speed-cup spindle is the pointer.

The rotational movement of the speed cup is retarded and held steady by the hair spring. The speed cup comes to rest at a point where the magnetic drag produced by the rotating magnet is just balanced by the retarding force created by the hair spring. An additional function of the hair spring is to pull the pointer back to the zero marking on the face dial when the magnet stops rotating.

There is no mechanical connection between the rotating magnet and the speed cup. As the rotational speed of the magnet increases due to vehicle acceleration, or to engine speed in the case of a tachometer, the magnetic drag on the speed cup also increases and pulls the speed cup further around, thereby indicating a faster speed by the pointer on the face dial. The magnetic field is constant and the amount of speed cup rotational deflection is at all times proportional to the speed at which the magnet is being revolved.

The rotating magnetic field generates minute eddy currents. The speed cup acts as an eddy-current torque unit and applies a torque to the pointer which is in direct proportion to the speed of rotation of the permanent magnet. In order to obtain a straight-line calibration of vehicle speed versus pointer deflection and to reduce pointer oscillation due to car bounce, it is essential that the speed cup be statically balanced prior to placement in a speedometer or a tachometer.

Each speed cup contains a certain amount of out-of-balance weight which varies from cup to cup and each cup may be statically balanced by either adding weight or removing weight. At

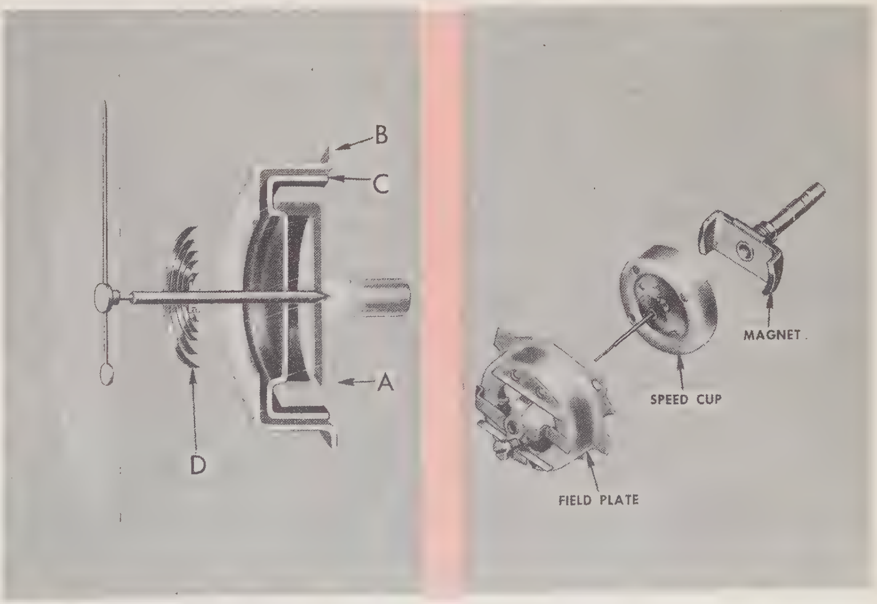


Fig. 1—The pointer of a speedometer or tachometer is actuated through the interaction of a rotating permanent magnet *A*, a stationary field plate *B*, a non-magnetic movable speed cup and spindle *C*, and a hair spring attached to the speed-cup spindle *D*.

AC Spark Plug Division, permanent static balance is achieved by punching three holes of equal diameter at specific angular positions on the outer rim of the cup. Originally, a balancing machine was used that punched one hole and then machined one larger diameter hole at the bottom side of the cup to the correct depth to just balance the cup. The depth of the hole was determined by the angular rotation of the cup resulting from punching the first hole. Because of mechanical difficulties encountered, this method was abandoned in favor of the three-punched-hole method. The use of three holes permits static balance to be achieved with holes of the same size and at the same radius.

The punching operation is done on a specially designed balancing machine. An unbalanced speed cup with attached spindle is placed in a supporting unit. The spindle rests horizontally on pivot-mounted roller bearings that oscillate parallel to the spindle length (Fig. 2). The oscillating roller bearings cause the heavy side of the cup to rotate downward

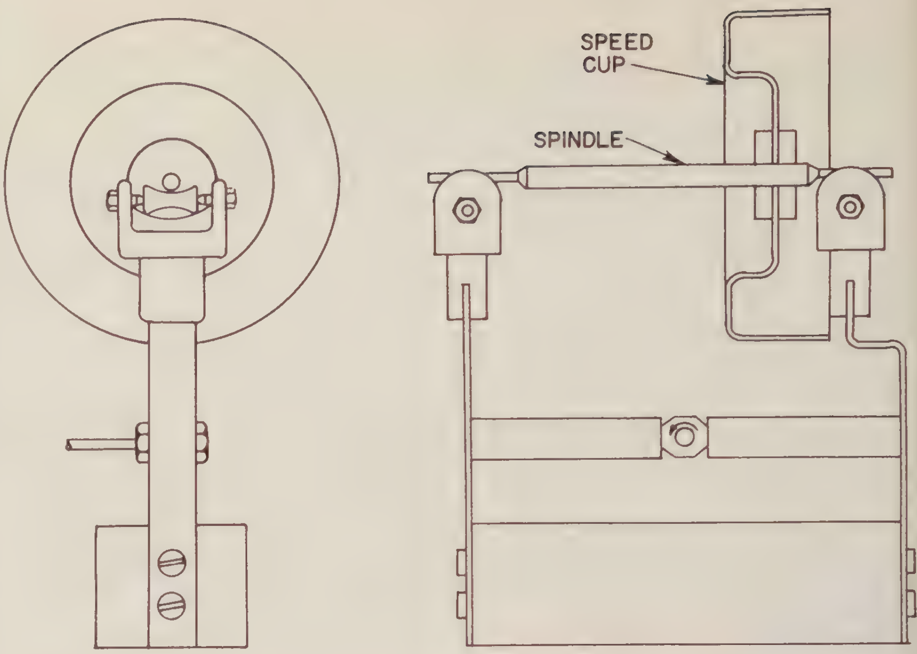


Fig. 2—The heavy side of the speed cup first must be determined prior to the hole punching operation. This is accomplished by placing the cup with attached spindle on oscillating roller bearings. The bearings oscillate parallel to the spindle length and cause the heavy side of the cup to rotate downward and rest at the bottom.

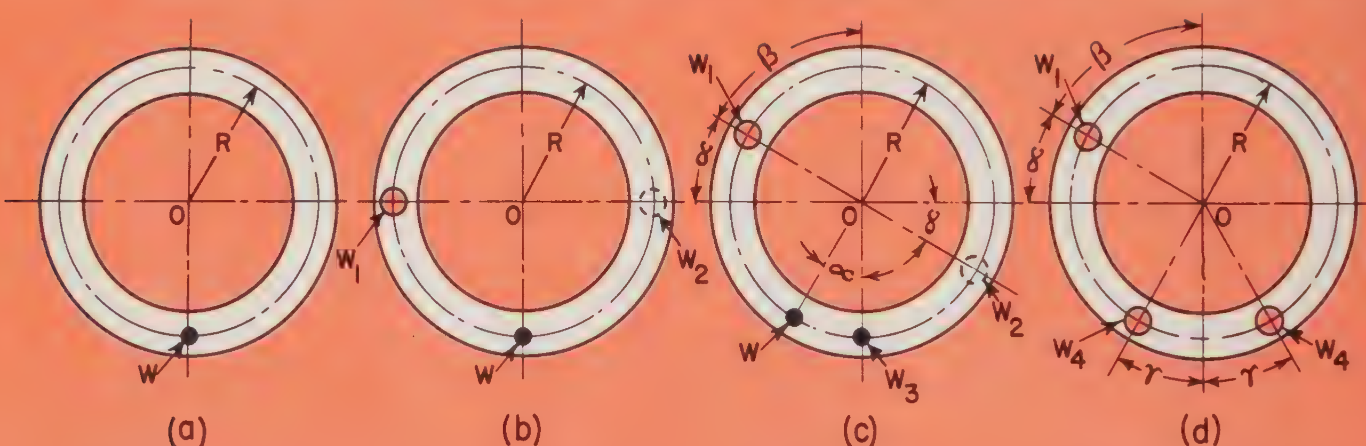


Fig. 3—When the speed cup and spindle are placed on oscillating bearings, the heavy side of the cup W rotates downward and rests at the bottom (a). One hole is then punched on the horizontal centerline of the cup and at right angles to the cup's heavy side. The punched hole removes a weight W_1 from the cup which is equivalent to adding an equal amount of weight W_2 on the opposite side (b). After the first hole is punched, the cup rotates through an angle α and a new heavy side of the cup W_3 rests at the bottom (c). A special indicating pointer, when moved through the angle β and lined up with the first punched hole, automatically positions the remaining two punches at the variable angle γ on each side of the vertical centerline (d). The two holes are then punched simultaneously, each removing a weight W_4 from the cup, and the balancing operation is completed.

and rest at the bottom. A fixture, to which the supporting unit is attached, contains three punches. Each punch is of the same diameter and removes an equal amount of weight. The three holes are punched on the same radius.

Fig. 3 shows the sequence of events during a punching operation. When the cup and spindle are placed in the supporting unit, the heavy side of the cup W rotates downward and rests at the bottom (a). W represents a weight at the radius R which, if removed, would exactly balance the cup. One hole is then punched, which removes a weight W_1 from the cup, on the horizontal centerline and at right angles to the heavy side (b). The punching operation for this hole is equivalent to adding an equal amount of weight W_2 on the opposite side of the cup. After the first hole has been punched, the cup turns through an angle α and a new heavy side W_3 rests at the bottom (c). The balancing machine is so arranged that an indicating pointer, when moved through the angle β to line up with the first punched hole,

automatically positions the remaining two punches at a variable angle γ (d). The two holes are then punched simultaneously, with each punch removing a weight W_4 from the cup, and the balancing operation is completed. W_4 is the same diameter as W_1, and is punched at the same radius R.

Problem

Using the angle α through which the cup turns after the first hole is punched as a measure of the out-of-balance of the cup, determine the angular position γ in terms of angle β at which the remaining two holes must be punched to complete the static balancing operation. The solution to the problem will appear in the January-February 1956 issue of the General Motors Engineering Journal.

Speedometer Speed Cup Available for Classroom Use with Problem

Engineering professors and instructors interested in obtaining a complimentary speedometer speed cup for classroom use may direct their requests to:

Department of Public Relations
AC Spark Plug Division
General Motors Corporation
1300 North Dort Highway
Flint 2, Michigan

Back Copies of the Journal Available

Extra copies of certain back issues in Volume I of the General Motors Engineering Journal are available to readers upon request. Copies may be obtained of the following issues:

- September-October 1953, Vol. 1, No. 2
- November-December 1953, Vol. 1, No. 3
- January-February 1954, Vol. 1, No. 4
- March-April 1954, Vol. 1, No. 5
- May-June 1954, Vol. 1, No. 6
- July-August 1954, Vol. 1, No. 7.

Requests may be directed to the Educational Relations Section, General Motors.

Contributors to Nov.-Dec. 1955 Issue of

GENERAL MOTORS Engineering JOURNAL

MAURICE D. ADAMS,

co-contributor of "How Sound Affects Vibration in Modern Aircraft Engines," has been a part-time employe of Allison Division during 1953 and 1954 in conjunction with the Allison program of summer employment for college professors. When first employed in 1953 he was serving as assistant professor of physics at Purdue University, in charge of the off-campus physics program at Indianapolis.

Mr. Adams received the B.S. degree in physics from Indiana State Teachers College in August 1926. He since has received a master's degree in education from the University of Pittsburgh and the M.S. degree in physics from Indiana University. He previously has been on the physics staff of Mississippi State College and Indiana University.

Coming to Allison primarily for engineering experience in industry to supplement his teaching, he has devoted most of his time to technical writing in the fields of sound and disc vibration.

Working in the highly specialized field of disc and gear vibration in turbo-jet engines, he has just completed for Allison an *Engineers Manual and Guide in the Testing and Analysis of Disc-Vibrations.*

Mr. Adams is affiliated with the American Association of Physics Teachers and the American Society for Engineering Education.

Growing out of the Allison experience and his increasing interest in the broader aspects of engineering education and the parallel field of technical education, Mr. Adams recently was promoted by Purdue University to become assistant head of Technical Institutes, with the rank of associate professor.

JOHN F. CURTIN,

contributor of "Applying the Principle of the Unit-Load to the Packaging of Automotive Hardware," is a packaging and loading engineer for Ternstedt Division, Trenton, New Jersey. He has served in this capacity since 1946.

Mr. Curtin's present major project is the study and development of packaging and loading techniques for automotive hardware. Previously, he worked on pallet improvement and standardization, packaging materials study and specification, and standardization of vendor's packaging materials for reuse. He joined General Motors in 1944 as an engineer in the Shipping Department of the Trenton Plant, Eastern Aircraft Division. Eastern Aircraft was a temporary GM organization during World War II established to consolidate GM's production of military aircraft.

Mr. Curtin has been very active in technical societies and committee work. He was a speaker at the 1955 National Packaging Conference of the American Management Association. In the 1953 Protective Packaging Competition of the Society of Industrial Packaging and Materials Handling Engineers, he was a national award winner. Mr. Curtin served as chairman of the Ternstedt Packaging Committee and serves on several General Motors Packaging Committees.

Sponsored by the Society of Industrial Packaging and Materials Handling Engineers, Mr. Curtin has completed a number of short courses, receiving certificates from Wayne University, Massachusetts Institute of Technology, and University of Illinois.

RICHARD R. FARLEY,

contributor of "Some Principles of Methods and Motion Study as Used in Development Work," serves the Process Development Section of the General Motors Manufacturing Staff as a senior project engineer in the Engineering Department. The Process Development Section's facilities are located at the General Motors Technical Center, Detroit.

Mr. Farley heads a group of engineers who are responsible for making studies and analyses of methods and motions and for the training of engineers in the use of these tools as they apply to manufacturing processes.

At present, Mr. Farley is engaged in conducting a methods consulting survey at the Bristol, Connecticut, plant of New Departure Division. He has completed similar surveys at the Sandusky, Ohio, plant of New Departure and at the Kokomo, Indiana, plant of Delco Radio Division.

In October 1953 Mr. Farley joined the Process Development Section as a project engineer. He was promoted to senior project engineer in June 1955. Prior to employment with General Motors, Mr. Farley was engaged as a consultant tool engineer and as a gage designer by two engineering organizations. He earned the B.S. degree in mechanical engineering in 1951 from the Lawrence Institute of Technology in Detroit.

Mr. Farley's military record includes service in the Navy from August 1945 until September 1946.

Mr. Farley is a member of the Engineering Society of Detroit.

WALTER B. HERNDON,

contributor of "The Manufacture of Planet Pinions," serves as works manager at the Detroit Transmission Division, Willow Run Plant, Ypsilanti, Michigan.

Mr. Herndon began his engineering career with General Motors in 1928 as a tool designer at the Cadillac Motor Car Division in Detroit. He later transferred to the Cadillac Engineering Department as a designer. He continued in this capacity until 1939 when he transferred to the Central Office Engineering Staff as a project engineer. When Detroit Transmission Division was formed in the same year, he transferred to the new Division's Engineering Department and later was made assistant to the general manager. Two years later he became assistant chief engineer at the same Division, serving in this position until 1949 when he was promoted to chief engineer. In 1952 he was appointed director of engineering and sales and one year later was named works manager. In this position, he supervised the establishment of manufacturing facilities at the Willow Run Plant when the Division moved in 1953.

Earlier in his engineering career, Mr. Herndon figured prominently in the initial design work and production of the Hydra-Matic automatic transmission. As a result of his extensive work in the field of automatic transmissions, Mr. Herndon has been responsible for twenty-two patent applications.

Mr. Herndon graduated in 1928 from the State College of Washington with the B.S.E. degree. He received the M.S.E. degree in 1930 from the University of Michigan.

He is a member of the Engineering Society of Detroit and the Society of Automotive Engineers, the latter having published his paper on "The Hydra-Matic Transmission" in the January 1952 *S.A.E. Quarterly Transactions*. Mr. Herndon also contributed a paper to the July-August 1954 issue of the General Motors Engineering Journal entitled, "An Application of Hydraulic Fundamentals: Development of the Hydra-Matic Automatic Transmission."

WILLIAM R. LULL,

co-contributor of "How Sound Affects Vibration in Modern Aircraft Engines," is a general engineering supervisor in the Experimental Test Section, Allison Division, Indianapolis, Indiana.

Mr. Lull attended Antioch College and has been with Allison since 1941. Since his employment, his principal assignment has been the study of vibration phenomena encountered in aircraft engines — including the historic Allison V-1710 power plant of World War II and the more recently developed turbo-jet and turbo-prop units.

Initially, he was a laboratory technician in the Vibration Group, conducting tests on engine roughness, aircraft mounts, crankshaft torsional vibration, and resonant vibration surveys of such installations as the P-40 and P-39 pursuit airplanes. Promoted to detail engineer in 1943 and experimental engineer in 1944, Mr. Lull was made responsible for applying to engine-development testing a variety of special test techniques and equipment, such as strain gages, stress-coat, sound level meters, frequency analyzers, torsiographs, multi-channel oscillography, pressure transducers, and torquemeters.

In 1950 he was promoted to senior experimental engineer, and in August 1952 he was made general supervisor of four engineering groups working on vibration, stress, instrumentation, and control problems.

HARRY G. McCALLUM,

contributor of "Development of an Improved Method for Cupola Charging to Meet Increased Production Requirements," is a plant layout engineer in Pontiac Motor Division's Planning and Standards Department.

Mr. McCallum's work at the Division encompasses a wide area of industrial engineering problems, most of which are related to material handling. In his present capacity, he serves as a materials handling equipment layout engineer in the V-8 Engine Plant. Previously, he was engaged as a time study man on the 4.5 aerial rocket and cargo carrier transmission.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

In January 1943 Mr. McCallum joined Pontiac Motor's Apprentice School as an apprentice tool maker. From June 1944 until April 1946 he was on military leave of absence, serving in the Army as an automatic rifleman and an automotive mechanic.

One year later, August 1947, Mr. McCallum enrolled at General Motors Institute, Flint, Michigan, and subsequently transferred to the Pontiac Motor foundry because of the fact that his specialization work at G.M.I. was to be primarily concerned with the application of industrial engineering methods to foundry problems. Mr. McCallum's paper in this issue is based on his study of the Division's foundry and his recommendations for a cupola charging system for use at the Division. His report, written in thesis form, fulfilled the requirements for the B.I.E. degree which was granted to him in 1952. In August of the same year he transferred to his present location—the Planning and Standards Department.

Mr. McCallum is a past member of the American Foundrymens Society.

STANLEY E. ROSS,

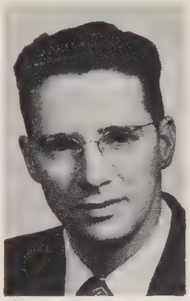
contributor of "Some Special Problems in Connection with Inventions in the Chemical Field" and co-ordinator of this issue's "Notes About Inventions and Inventors," is a patent attorney supervisor in the General Motors Patent Section. He is assigned to the Patent Section's Central Office, located in Detroit, Michigan. Two other offices are at Dayton, Ohio, and at Washington, D.C.

Mr. Ross's duties include responsibility for patent matters involving the preparation of patent applications for inventions developed by General Motors employes, the investigation of infringement and validity considerations on new or changed devices and processes used in production, and the development of license agreements pertinent to devices used in production. The technical areas covered by Mr. Ross's work are in the allied fields of metallurgy, plating, metal working, bearings, chemistry, foundry processes, and metal cleaning.

Michigan State College (now Michigan State University of Agriculture and Applied Science) granted him the B.S. degree in 1926. That same year, he entered employment with Buick Motor Division, Flint, Michigan, as a metallographer. In 1930 he left General Motors to earn the LL.B. degree from George Washington University (1934), and at the same time he performed the duties of an examiner in the U.S. Patent Office, Washington, D.C. In 1936 he returned to General Motors as a patent attorney in the Patent Section, Central Office.

Mr. Ross is a member of Phi Lambda Tau, Gamma Eta Gamma, the American Bar Association, the Michigan and District of Columbia Bars, the American Patent Law Association, and serves as chairman of the Chemical Practice Committee of the Michigan Patent Law Association.

ALBERT F. WELCH,



contributor of "Instruments Are the Tools of Research," serves the General Motors Research Staff as an assistant department head in the Instrument Section of the Technical Facilities and Services Department. In addition to instrument and dynamometer service, this Department is responsible for the design and construction or selection and purchase of specialized instrumentation for the Research Staff's activites located at the General Motors Technical Center.

Mr. Welch has served both the Research Staff and Cadillac Motor Car Division during his seven years with General Motors. Initially, he joined the Research Staff's Physics and Instrumentation Department as a junior engineer in July 1948, directly after earning the B.S.E.E. degree from Tufts College in Medford, Massachusetts. Two years later he was promoted to research engineer.

From January 1951 to September of the same year, Mr. Welch was located at Cadillac Motor Car where he did instrumentation work in the Engineering Department. In September he returned to the Research Staff as a senior project engineer in the Instrument Section, was promoted to supervisor in October 1952, and made assistant department head—his present position—in January 1954.

Mr. Welch's research on instrumentation has led to one granted patent for a pressure indicator.

His technical committee work includes membership in the Society of Automotive Engineers' Committee on Thermal Measuring Systems. In addition, he is a member of the Instrument Society of America and Tau Beta Pi.

JOHN M. WHITMORE,

co-contributor of "How Sound Affects Vibration in Modern Aircraft Engines," is head of the Experimental Electronics and Parts Test Department in the Aircraft Engines Operations of Allison Division. Mr. Whitmore began his career with General Motors in 1937 as a sound and instrument engineer at the General Motors Proving Ground at Milford, Michigan. After approximately three years of automotive sound and vibration work, he was transferred to Allison in 1940. His first assignment there was that of a design engineer, working to eliminate torsional and linear vibration in the Allison V-1710 engine.

In 1944 he was transferred to the Experimental Department to work on experimental vibration and associated phenomena, as well as instrumentation for same. This work naturally led into the added fields of stress, statics, overspeed spinning, analogues of vibration problems, and electronics in instrument development. This work continued to expand as new processes and techniques

The General Motors Engineering Journal is a publication designed primarily for use by college and university educators in the fields of engineering and the sciences. Educators in these categories may, upon request, be placed on the mailing list to receive copies regularly. Classroom quantities also can be supplied regularly or for special purposes, upon request to the Educational Relations Section, General Motors.

were added until it led to Mr. Whitmore's present position as head of the Experimental Electronics and Parts Test Department which is basically a development organization concentrating on specialized problems using the most advanced techniques in their solution. Under the direction of Mr. Whitmore, Allison was among the very first to use an analogue in the solution of torsional vibration problems, to record temperature and stress on a turbine bucket in operation, and one of the few to use sound extensively in fatigue studies.

Mr. Whitmore received his electrical engineering degree from The Ohio State University in 1936, after which he spent two years in radio interference reduction engineering for the Ohio Power Company in Steubenville, Ohio.

Mr. Whitmore also has been active on the Aircraft Industries Association Noise Control Committee for the past five years where he served as chairman of the subcommittee which formulated *Standard Practices for the Measurement of Aircraft Noise*. In addition, his laboratory work has resulted in several granted patents.

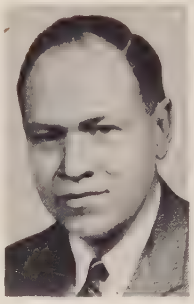
GEORGE A. WIDMOYER,

who prepared the problem "Determine the Basic Design Specifications for a Ball Bearing Screw Assembly" and the solution appearing in this issue, is a designer in the Product Engineering Department of Saginaw Steering Gear Division, Saginaw, Michigan.

Mr. Widmoyer joined Saginaw Steering Gear in June 1953 as a college graduate-in-training. Seven months later he was promoted to junior designer, and in March 1955, assumed his present position.

In 1943 Mr. Widmoyer entered the United States Army, where he served as an infantry scout in Southern France. He was awarded three campaign stars and the Purple Heart. Upon separation from the service in 1946 he entered Bay City Junior College, Bay City, Michigan, receiving the Arts and Sciences degree in 1948. Following his graduation, Mr. Widmoyer was employed by the Visilite Corporation of Saginaw, Michigan, as a router operator. From 1951 to 1953 Mr. Widmoyer attended Valparaiso University, Valparaiso, Indiana, where he earned the B.S.M.E. degree.

Mr. Widmoyer's previous projects at Saginaw Steering Gear include design work in ball bearing automotive seat actuators and ball bearing top-lift assemblies for convertibles. At the present time, Mr. Widmoyer is serving as stress and design engineer on ball bearing actuators.



WILLIAM N. WITHERIDGE,

contributor of "Manufacturing Engineers Develop Specifications for Resistance Welding Controls," is assistant director of the Production Engineering Section of the GM Manufacturing Staff.

He first joined GM in 1927 as an apprentice tool maker with a former Division of General Motors, Saginaw Crankshaft Division, Saginaw, Michigan, and in 1930 transferred to Oldsmobile Division as a tool and machine designer. He was graduated from General Motors Institute in 1931. In 1935 Dr. Witheridge received the B.S.M.E. degree from Michigan State University of Agriculture and Applied Science. He continued his formal education by attending Harvard University, where he received the M.S. degree in engineering in 1936, and then served as an instructor in air conditioning for two years.

From 1938 to 1946 he was ventilation engineer and director of industrial health engineering for the City of Detroit. He became ventilation consultant for GM in 1946, serving both the General Motors Research Staff and the Personnel Services Section of the Central Office. He was awarded the Ph.D. degree in engineering from the University of Michigan in 1951. In 1953 Dr. Witheridge was made supervisor of equipment and operations for the Production Engineering Section of the Manufacturing Staff, and in April 1954 he was promoted to his present position.

Dr. Witheridge is a member of a number of technical societies, including the American Institute of Industrial Engineers, American Society of Heating and Air Conditioning Engineers, Air Pollution Control Association, and American Association for the Advancement of Science.

GM Educational Aids for Classroom Use

As a result of numerous requests from educators, many educational aids have been developed by General Motors both for classroom use and as information to supplement textbook material.

Of particular interest to engineering educators are teaching aids in such technical fields as—automotive, electrical, Diesel engines, and refrigeration, as well as manufacturing processes and engineering drawing. The Educational Relations Section of General Motors Department of Public Relations serves as a clearing point in GM to assist educators in securing these aids.

Typical of the aids available are motion picture films and filmstrips on a variety of technical subjects including the basic principles of the internal combustion engine, lubrication, chemical stability in refrigeration systems, ignition systems, and the manufacture of ball bearings. For a complete listing of films and filmstrips the "General Motors Film Catalog" is available free to educators on request.

In addition to films and filmstrips General Motors also has available numerous manuals and handbooks which explain the theory, operation, and maintenance of automotive components. While these publications are primarily technical in nature, a number of others are available in booklet form which treat technical subjects in a more popular flavor. Some examples of these are "A to Zero of Refrigeration," "Optics and Wheels," Electricity and Wheels," and "Precision —A Measure of Progress."

While single copies of the educational aids mentioned are free, some other aids available from General Motors involve a nominal charge. For additional information on these and other educational aids a brochure entitled "How to Obtain General Motors Educational Aids" is available to educators on request to:

Educational Relations Section
Department of Public Relations
General Motors Corporation
P.O. Box 177, North End Station
Detroit 2, Michigan.

GENERAL MOTORS

Engineering JOURNAL

index to volume 2

General Motors Engineering Journal

January-February 1955 to November-December 1955

Published by General Motors Corporation
Detroit 2, Michigan

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5 September-October 1955

6 November-December 1955

Example: 3-44 means page 44 of the May-June 1955 issue.

Abbreviations

(CP) Classroom problem

(Ed) Editorial—always appears on unnumbered inside front cover

(I) Inventor

(P) Portrait

A

BACK ISSUES: Readers may obtain back issues of the GENERAL MOTORS ENGINEERING JOURNAL as available upon request to the Educational Relations Section.

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COMBUSTION CHAMBER STUDY

This high-speed photographic equipment is used by GM engineers to compare the turbulence induced by different Diesel engine combustion chamber designs.

To assure smooth combustion, certain turbulence characteristics of air being compressed in the cylinder of a Diesel engine are desirable. Since combustion chamber design is one factor controlling turbulence, the Power Development Section of the General Motors Engineering Staff devised this method for studying the effect of various combustion chamber shapes, applying a simplified analogy to the actual complex situation.

In a plastic cylinder model, air molecules are represented by aluminum dust floating on water which reflects light sufficiently to enable high-speed photography of the swirl patterns induced by the piston. Exposing 64 frames per second, a movie camera of the type ordinarily used in sports photography records the changing aluminum-dust swirl patterns for detailed study at projection speeds of 16 frames per second.

Test results leading to choice of combustion chamber configuration are analyzed relatively rather than absolutely because of experimental differences—such as surface tension of the water—not encountered in the engine itself. Results of this test correlated highly with actual engine tests.

GENERAL MOTORS

Engineering

JOURNAL